GUIDANCE FOR INCINERATOR DESIGN AND OPERATION

VOLUME 1

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Jim Bradley
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VOLUME I

GENERAL

ONTARIO MINISTRY OF THE ENVIRONMENT
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M4V 1P5

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FOREWARD

This publication is one of a series of documents dealing with incinerator design and operation that have been prepared by the Ontario Ministry of the Environment. The other publications that are or will be available are:

° "Guidance for Incinerator Design Operation, Summary and Update."

° "Guidance for Incinerator Design and Operation, Volume II, (Biomedical Waste Incinerator)",

° "Guidance for Incinerator Design and Operation, Volume III (Crematoria)", and

° "Guidance for Incinerator Design and Operation, Volume IV (Cremators for Animal Shelters)".

The mention of trade names or commercial products in the report does not constitute endorsement or recommendation for use.

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Chapter 1
INTRODUCTION

The purpose of this report is to provide guidance to ensure that incinerators proposed for installation and operation in the Province will be well designed and comply with the Ministry's standards and guidelines. This report is also intended to be used in the evaluation of incinerator designs and applications for approval by the Ministry.

The Ontario Ministry of the Environment has initiated a major program of financial and other support to set up, operate and promote recycling programs, and has adopted a cautious approach to waste incineration. Each proposed incinerator will be assessed on its own merits, and will be approved only if it is clear that the environment will be protected.

Chapter 2 discusses applicable legislation and regulations governing incinerator installations and reviews the provincial approvals process.

Chapter 3 discusses the equipment available for handling wastes and the layout of that equipment. These front-end systems determine, to a large degree, the efficiency and utility of an incinerator. Safety considerations and recordkeeping are also discussed in this chapter.

Chapters 4, 5, and 6 present design evaluation techniques for combustion chambers, heat recovery equipment, and emission control devices, respectively. These techniques can be used to evaluate a design for effectiveness and impact on the environment.

A bibliography of pertinent sources is included as Chapter 7.

Appendix A provides a glossary of terms relative to incineration. Appendix B contains supplementary regulatory and approvals information including Ministry Policies related to incineration, addresses of Ministry offices and sample Application forms for Certificates of Approval. Appendix C provides the technical data and procedures required to perform incinerator calculations and presents illustrative examples.

CHAPTER 2
ENVIRONMENTAL LEGISLATION/REGULATIONS

2.1 INTRODUCTION

The complexity of the approval process for the design, construction, installation, operation, and modification of an incinerator depends largely on the type of wastes accepted by the incinerator, where these wastes originate, and how they are ultimately disposed of. This chapter presents an overview of the federal, provincial, and municipal requirements for incinerator applications as well as a brief discussion of the approvals process. The information provided in this chapter is not intended as an exhaustive review of the legislative and approval requirements. In addition, the legislative and administrative requirements for incinerators, as well as other emission sources, are currently under review in Ontario. For example, the Ontario Ministry of the Environment has initiated the MISA (Municipal and Industrial Strategy for Abatement) and the CAP (Clean Air Program) initiatives to virtually eliminate the emission of toxics to the environment. It is the prime responsibility of the proponent to determine the specific requirements which must be met prior to the establishment of an incineration facility.

2.2 APPLICABLE LEGISLATION

2.2.1 Federal Legislation

Principal federal legislation, regulations, and guidelines affecting incinerator emissions include the following:

- Canadian Environmental Protection Act (CEPA)

- Ambient Air Quality Objectives (No. 1, No. 2, and No.3)

- Packaged Incinerators National Emission Guidelines

- National Building Code of Canada 1985, Sections 3.5.2.5; 3.5.2.7; 6.2.6; 9.10.10.7; and 9.10.10.10

The CEPA empowers the Minister of Environment to formulate ambient air quality objectives and prescribe national emission standards and guidelines establishing the maximum quantities of air contaminants that may be emitted into the air by stationary sources.

The ambient air quality objectives under the CEPA prescribe the desirable, acceptable, and tolerable ranges of ambient air quality with respect to sulphur dioxide, suspended particulate matter, carbon monoxide, ozone, and nitrogen dioxide.

The Packaged Incinerators National Emission Guidelines limit the quantities of particulate matter, hydrogen chloride, and sulphur dioxide which may be emitted into the ambient air from new installations of packaged incinerators. Packaged incinerator means any furnace used in the process of burning solid waste whose maximum burning rate does not exceed 900 kg/h. These guidelines state that gases discharged to the atmosphere as a consequence of the operation of a new installation should not:

a) exhibit visible emissions which exceed zero opacity;

b) contain particulate matter in excess of 0.75 g/kg of solid waste burned;

c) contain hydrogen chloride in excess of 100 ppm on a dry basis and corrected to 50% excess air; and

d) contain sulphur dioxide in excess of 250 ppm on a dry basis and corrected to 50% excess air.

For existing installations, gases discharged to the atmosphere should not exhibit visible emissions which exceed 20% opacity.

The National Building Code specifies standards of service rooms and chimney flues for indoor incinerators. Service rooms containing an incinerator shall be separated from the remainder of the building by a fire separation having a fire-resistance rating of at least 2 hours. However, it shall not contain other fuel-fired appliances. If the room is installed with swing-type doors, they shall swing outward except when the doors open on a corridor or any room, then they shall swing inward. Every incinerator shall be served by a chimney flue conforming to the National Building Code. The design, construction, installation, and alteration of every indoor incinerator shall conform to the National Fire Protection Act, 1982 under "Incinerators, Waste and Linen Handling System and Equipment."

The above act, objectives, guidelines, and codes should be consulted for any federal works, undertakings, or business related to the design, construction, installation, or alteration of incinerators.

2.2.2 Provincial Legislation

There are three provincial acts that apply to the environmental aspects of establishing an incineration facility in Ontario, namely:

- The Environmental Assessment Act (EAA);
- The Environmental Protection Act (EPA); and
- The Ontario Water Resources Act (OWRA).

It should be noted that the above Acts and the Regulations thereunder apply not only to an incineration facility, but also to any other sources of contaminant emissions.

Prior to the construction of an incineration facility, the proponent is required to submit applications to the Ministry of the Environment (MOE) to obtain one or more Certificates of Approval. Depending on the type and quantity of waste to be incinerated, public hearings may have to be held as part of the approvals requirements. This section provides a discussion of the types of Certificate of Approval required, the various Regulations in the Acts that apply to such a facility, and an outline of the procedures used to evaluate an application for a Certificate of Approval.

The Environmental Protection Act (EPA)

This Act and the two (2) principal Regulations written under the EPA (Regulations 308 and 309) are intended to provide for the protection and conservation of the natural environment.

Part II, Section 8 of the EPA is concerned with air quality and requires the proponent to submit an application to the MOE and obtain a Certificate of Approval (Air) from the Director of the Approvals Branch prior to the construction of an incineration facility, for the methods or devices or both to be employed to control or prevent the emission of any contaminant into any part of the natural environment.

Regulation 308, the General Air Pollution Regulation, sets out the maximum allowable point of impingement air concentration for contaminants that may result from a point source of emission. The point of impingement refers to a point where the plume from a source of emission impinges on a critical or sensitive receptor such as a building, structure, or the ground. Regulation 308 also includes the method of calculation to be used in arriving at point of impingement concentrations. Point of impingement standards have been established for 100 contaminants (e.g. suspended particulate, SO_2, CO, NO_X, and HCl). Moreover, tentative standards, guidelines, and/or provisional guidelines have also been provided for more than 100 other compounds (e.g. PCBs, chlorinated dibenzodioxins, and furans). Copies of the current list of tentative standards, guidelines, and provisional guidelines are available from the Air Resources Branch, 880 Bay Street, Toronto M5S 1Z8, Telephone (416) 965-5776.

Regulation 308 also has requirements regarding opacity; also abnormal operation; incinerator capacity; and an incinerator organic matter emission limit of 100 ppm expressed as methane.

Part V of the EPA deals with waste management and Section 27 stipulates that no person shall use, operate, establish, alter, enlarge, or extend a waste management system or a waste disposal site unless a Certificate of Approval or a provisional Certificate of Approval has been issued by the Director and accepted in accordance with any conditions set out in such Certificate.

Policies 01-01 and 01-03 (see Appendix B) apply to new refuse incinerators that burn one or a combination of domestic, commercial, or non hazardous solid industrial wastes. Policy 01-01 "Combustion in Incinerators" establishes design and operating guidelines, and policy 01-03 "Air Pollution Control on Incinerators" requires the installation of state-of-the-art air pollution controls on all new refuse incinerators. An interim guideline prepared for discussion purposes in interpreting this policy establishes emission limits for particulate matter and hydrogen chloride for these incinerators.

The General Air Pollution Regulation prohibits the operation of existing apartment incinerators as of May 31, 1989.

The Ontario Water Resources Act (OWRA)

The OWRA was enacted to ensure effective management of Ontario's water resources and to maintain water quality at a level that is satisfactory for aquatic life and recreational use. Section 24 of the OWRA is concerned with water quality and the discharge of wastewaters into a watercourse (e.g. lake, river, stream). This Section requires the submission of plans, specifications, and an engineering report of the works to be undertaken, and the location of the effluent discharge together with such information as the Ministry may require for a technical review prior to the issuance of the Certificate of Approval.

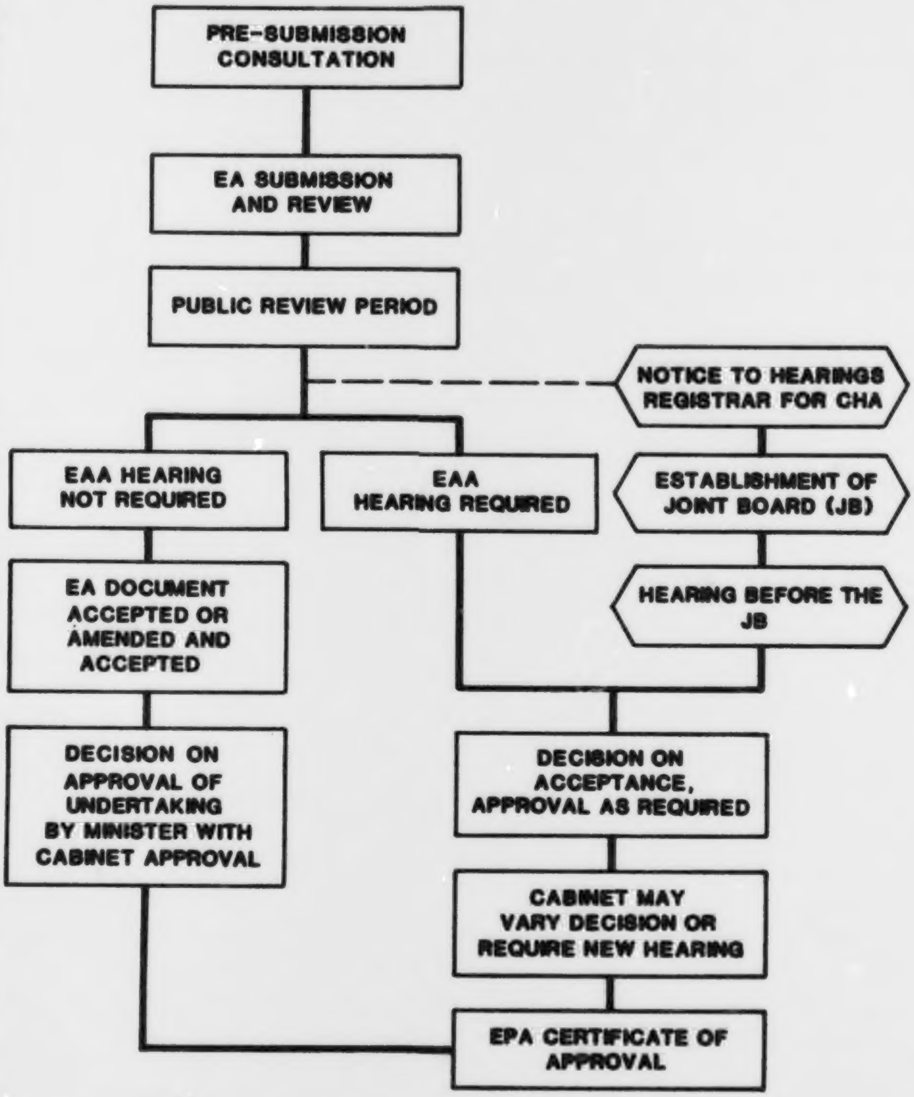
Effluent discharge requirements are established on a case-by-case basis taking into account the characteristics of the receiving water body and consistent with MOE's water management goals, policies, objectives, and implementation procedures. If the effluent is discharged to a sanitary sewer, compliance with the local sewer bylaw as well as concurrence from the municipality involved are required; however, approval from the Ministry for the discharge is not necessary. The municipality may approach the Ministry for advice regarding the acceptability of discharge into the sanitary sewer.

The Environmental Assessment Act (EAA)

The Environmental Assessment Act is intended to promote good planning, informed decision-making, and ultimately the protection of the environment by requiring proponents to put forward for approval undertakings which have an acceptable balance of advantages and disadvantages. This involves considering a broad range of alternatives, looking at the net environmental effects as well as the advantages and disadvantages to the environment of each alternative, and then narrowing down the range to the preferred alternative. In approving the undertaking (project), the advantages have to be seen to outweigh the disadvantages in achieving the purpose of the EAA.

A project which is subject to the EAA may not proceed until the Minister has accepted the EA and the undertaking has been approved. Approvals, licences, grants, loans, orguarantees under other legislation and regulations cannot be given prior to approval under the EAA.

The hearings and approvals process under the Environmental Assessment Act is outlined in Figure 2-1. Under the EAA, a hearing is optional at the discretion of the Minister. Should a hearing be required, it will be conducted by either the Environmental Assessment Board or the Consolidated Hearings Board, depending upon the nature of the approvals required.


PRE-SUBMISSION CONSULTATION
EA SUBMISSION AND REVIEW
PUBLIC REVIEW PERIOD
NOTICE TO HEARINGS REGISTRAR FOR CHA
EAA HEARING NOT REQUIRED
EAA HEARING REQUIRED
ESTABLISHMENT OF JOINT BOARD (JB)
EA DOCUMENT ACCEPTED OR AMENDED AND ACCEPTED
HEARING BEFORE THE JB
DECISION ON APPROVAL OF UNDERTAKING BY MINISTER WITH CABINET APPROVAL
DECISION ON ACCEPTANCE, APPROVAL AS REQUIRED
CABINET MAY VARY DECISION OR REQUIRE NEW HEARING
EPA CERTIFICATE OF APPROVAL

NOTE :

- The CHA Board decision can be appealed to Cabinet
- The Director's decision on the Certificate of Approval may be appealed to the Environmental Appeal Board

EAA - Environmental Assessment Act
EPA - Environmental Protection Act
CHA - Consolidated Hearing Act

⬡ - OPTIONAL

Figure 2-1

SIMPLIFIED REPRESENTATION OF THE HEARINGS AND APPROVALS PROCESS FOR WASTE MANAGEMENT UNDERTAKINGS WHEN AN ENVIRONMENTAL ASSESSMENT IS REQUIRED

Once approval has been granted by either the Minister or the Board, the proponent can proceed with specific EPA approvals.

The definition of environment in the EAA (clause 1(c)) provides the scope of inquiry required for the evaluation of each alternative leading to the selection of the preferred alternative. Environment includes social, cultural, economic, natural, and technical components.

On March 13, 1987, the Ontario Government indicated that public and private waste incineration facilities will be subject to the same legislative and approvals requirements.

The following facilities are subject to the Environmental Assessment Act:

- hazardous waste incinerators;
- liquid industrial waste incinerators; and
- municipal and/or non-hazardous industrial waste incinerators which burn 100 tonnes or more per day.

The EA Act requires a reasonable planning effort, taking into consideration the proponents' nature, aims, resources and capabilities.

If a project is subject to the EAA, the proponent must submit an Environmental Assessment document (EA) to the Minister of the Environment for acceptance and approval. Upon receipt of the EA, the Ministry circulates the document to all appropriate government agencies (including the

Medical Officer of Health, Conservation Authority, and Environment Canada) for their comments and concerns. The Ministry prepares a government review which is meant to address the quality of the EA by providing a balanced evaluation. After the review is published, a public notice is given to provide all interested parties and the public the opportunity to comment on the EA and the review.

The EAA specifies the minimum requirements of the content of an EA that is submitted (subsection 5(3) of the Act) and this includes the evaluation of the net environmental effects and advantages and disadvantages to the environment of each alternative to the undertaking and alternative method of carrying out the undertaking.

Public participation and consultation with members of the government review team are key ingredients in the planning of a waste facility. This consultation is discussed in more detail in the Ministry's Guidelines for Pre-Submission Consultation Associated with the Environmental Assessment Act.

Further information on the EA process and requirements is available from the Ministry in the "General Guidelines for the Preparation of Environmental Assessments."

2.2.3 Municipal Requirements

Proponents wishing to install and operate an incineration facility should contact the municipality in which the incinerator is located. Generally, Ontario municipalities do not have specific bylaws regulating the design and operation of incinerators.

Most municipalities require plans and specifications to comply with relevant sections of the National Building Code, as outlined in Appendix B.

In addition, the proponent should consult the municipality on bylaw requirements relating to noise, hours of operation, zoning, and odour. In the event that wastewater is to be discharged to a municipal sewer as a result of the incinerator operation, the concurrence of the municipality is required and the proponent should consult the local sewer bylaw requirements for wastewater discharge.

2.3 APPROVALS PROCESS

2.3.1 Procedures Used to Evaluate Applications for Certificates of Approval under the EPA and OWRA

Upon receipt of the applications and the supporting information, including plans, specifications, and design details, a technical review of all units of the systems for the collection, treatment, and control of emission of contaminants will be carried out in order to determine if the proposed facility complies with the Ministry's requirements. A simplified flow chart for approvals under the EPA and the OWRA is illustrated in Figure 2-2.

Air Emissions

For approvals under Section 8 of the Environmental Protection Act, dispersion calculations are carried out to ascertain if the emissions from the proposed facility would comply with the point of impingement concentration standards (Regulation 308) and/or guidelines at the critical receptors. A heat and material balance calculation is

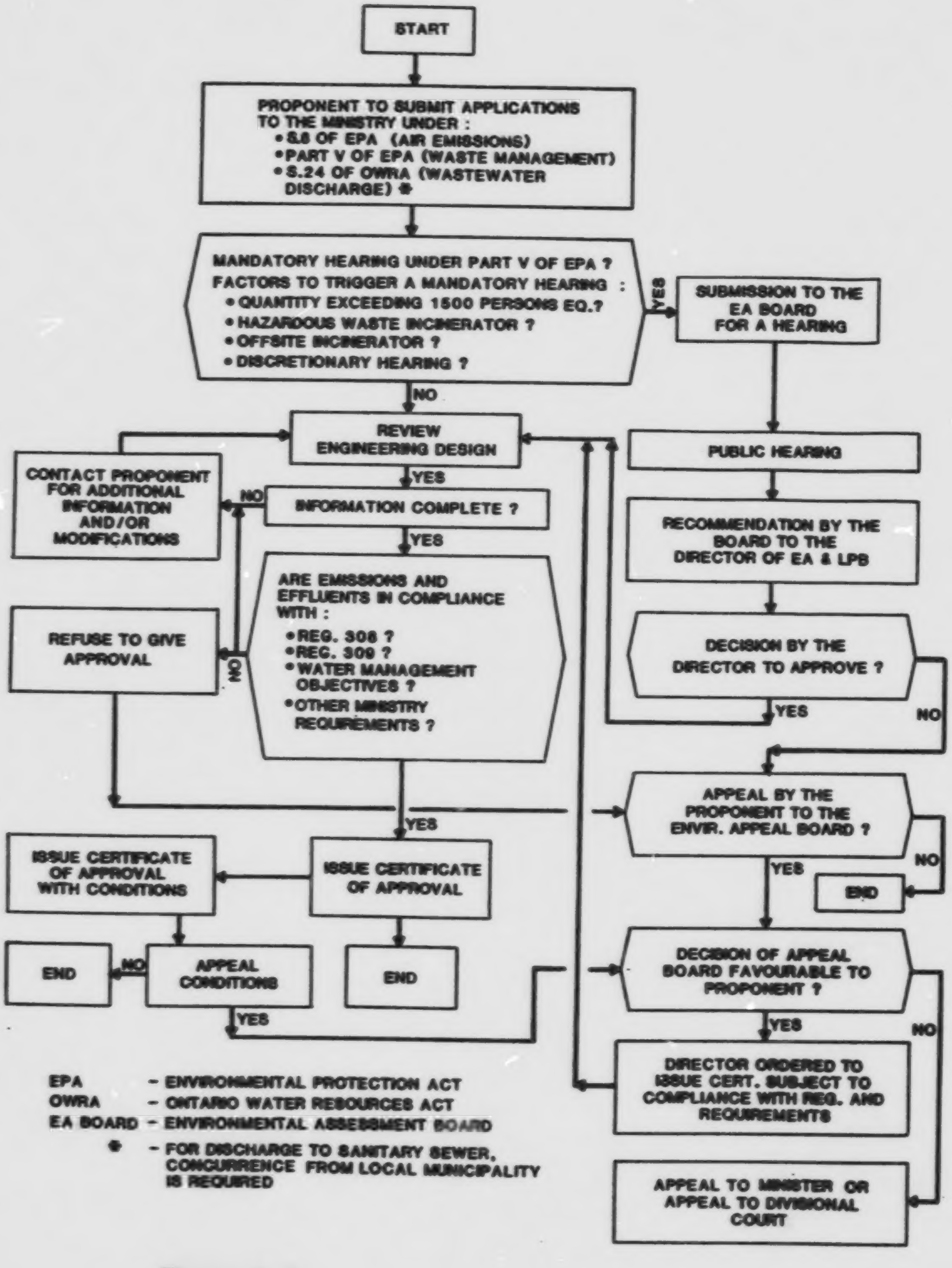

START
PROPONENT TO SUBMIT APPLICATIONS TO THE MINISTRY UNDER :
• S.8 OF EPA (AIR EMISSIONS)
• PART V OF EPA (WASTE MANAGEMENT)
• S.24 OF OWRA (WASTEWATER DISCHARGE) *
MANDATORY HEARING UNDER PART V OF EPA ?
FACTORS TO TRIGGER A MANDATORY HEARING :
• QUANTITY EXCEEDING 1500 PERSONS EQ.?
• HAZARDOUS WASTE INCINERATOR ?
• OFFSITE INCINERATOR ?
• DISCRETIONARY HEARING ?
YES
SUBMISSION TO THE EA BOARD FOR A HEARING
NO
REVIEW ENGINEERING DESIGN
PUBLIC HEARING
CONTACT PROPONENT FOR ADDITIONAL INFORMATION AND/OR MODIFICATIONS
YES
NO
INFORMATION COMPLETE ?
RECOMMENDATION BY THE BOARD TO THE DIRECTOR OF EA & LPB
YES
ARE EMISSIONS AND EFFLUENTS IN COMPLIANCE WITH :
• REG. 308 ?
• REG. 309 ?
• WATER MANAGEMENT OBJECTIVES ?
• OTHER MINISTRY REQUIREMENTS ?
REFUSE TO GIVE APPROVAL
NO
DECISION BY THE DIRECTOR TO APPROVE ?
YES
NO
APPEAL BY THE PROPONENT TO THE ENVIR. APPEAL BOARD ?
YES
ISSUE CERTIFICATE OF APPROVAL WITH CONDITIONS
ISSUE CERTIFICATE OF APPROVAL
YES
NO
END
END
NO
APPEAL CONDITIONS
END
DECISION OF APPEAL BOARD FAVOURABLE TO PROPONENT ?
YES
YES
NO
DIRECTOR ORDERED TO ISSUE CERT. SUBJECT TO COMPLIANCE WITH REG. AND REQUIREMENTS
APPEAL TO MINISTER OR APPEAL TO DIVISIONAL COURT
EPA - ENVIRONMENTAL PROTECTION ACT
OWRA - ONTARIO WATER RESOURCES ACT
EA BOARD - ENVIRONMENTAL ASSESSMENT BOARD
* - FOR DISCHARGE TO SANITARY SEWER, CONCURRENCE FROM LOCAL MUNICIPALITY IS REQUIRED

Figure 2-2

SIMPLIFIED REGULATORY APPROVALS PROCESS UNDER THE ENVIRONMENTAL PROTECTION AND THE ONTARIO WATER RESOURCES ACTS

also performed to determine if the facility would meet the specified temperature and retention time requirements.

The point of impingement concentrations are calculated in accordance with the Appendix of Regulation 308. The Regulation provides three formulae to be used for the dispersion calculation and the choice of a proper dispersion model is mainly based on the height of the stack relative to that of the building on which the source of emission is located and the proximity to the critical receptors.

Wastewater Discharge

If the wastewater is to be discharged to a receiving stream or natural watercourse, the quality of the effluent should comply with the requirements set out in the Ministry "Water Management, Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment, November, 1978, revised May, 1984." Effluent requirements are established on a case-by-case basis, and take into consideration the characteristics of the receiving water body or "mixing zone". Mixing zone is defined as an area of water contiguous to a point source where the water quality does not comply with the Provincial Water Quality Objectives. The size of the mixing zone is determined on a case-by-case basis and is to be minimized to the greatest possible degree and under no circumstances is the mixing zone to be used as an alternative to treatment.

Ash Disposal

Ashes produced by all incinerators should be tested by the leachate extraction procedure to determine how they should be managed.

CHAPTER 3
GENERAL CRITERIA

3.1 WASTE RECEIPT AND HANDLING

3.1.1 Waste Receipt

3.1.1.1 Municipal Solid Waste

Weighing Facilities. Weighing of incoming municipal waste is necessary to determine the quantity of wastes received and to help regulate the operation of the facility.

There are three types of scales in general use for weighing the wastes: beam weight, load cell, and combination mechanical/electronics scales.

In selecting a scale, a 45-tonne (50-ton) capacity is usually adequate. Platforms 3 m (10 ft) wide by 10 m (33 ft) long are sufficient for weighing packer trucks. However, if tractor-trailer transfer vehicles will be bringing wastes to the facility, a 15-m (50-ft) platform length is required. Adequate provisions should be made for signal lights, curbing and drainage, alarms, and automated recording devices.

Information that should be recorded when trucks are weighed includes:

- Date and time
- Vehicle identification

- Tare weight
- Gross weight
- Net weight (gross weight less tare)

The scale system must be adequate to handle the maximum expected number of vehicles without excessive delays or backups. With an automated system, approximately one truck can be weighed each minute, or 60 trucks per hour per scale.

3.1.1.2 Industrial Waste

Waste Receiving Area. The type and nature of industrial waste received at an incinerator facility will dictate the design and equipment within the waste receiving area. The physical types of hazardous waste that may be received are:

- Bulk liquid
- Containerized materials (liquid and solids)
- Dry solid materials
- Wet solid materials (pumpable and non-pumpable)

The types of receiving equipment for unloading can be divided into three general areas:

- Pumpable liquid transfer
- Container transfer

- Bulk solids transfer

Liquids Unloading. Liquids can arrive in bulk in tank cars or tank trucks by either truck or rail. Standard rail tank cars vary in capacity from 23 to 100 m^3 (5,062 to 22,000 I gallons), and tank trucks carry up to 38 m^3 (8,400 I gallons).

The site should be arranged, through the use of either natural grade or diversionary dikes or drains, so that escaping liquid will flow to a safe location. When possible, 15 m (50 ft) or more of clear space should be provided between unloading stations and buildings.

Pumpable materials can be transferred through piping by pump, gravity flow, or compressed-gas displacement. Pumping systems are most commonly used and have an inherent safety advantage in that they can be designed so that the flow of liquid ceases when the pump is stopped.

The safest method of unloading a tank car or truck is through the top by means of a pump with extended suction. Tank trucks, however, are usually unloaded from the bottom by gravity or by pumps mounted on the vehicle. Positive-displacement pumps are the preferred method for transferring liquid wastes. Centrifugal pumps may be suitable for service where the vapour pressure of the waste is not exceeded by the pump suction.

Spill and Runoff Containment. Drainage from the unloading area should be collected or diverted to permit recovery or, at least, proper disposal of any spills or runoff. The basic objective of containment is to prevent the discharge of hazardous materials to waterways, sewer systems, or groundwaters.

Container Unloading. Containerized hazardous waste is most likely to arrive for unloading via rail boxcar or truck semitrailer. A 200-1 (44-I gallon) drum is the most popular form of container; a boxcar can carry 360 such drums per carload.

Bulk Solids Unloading. Bulk solids for incineration generally arrive for unloading in hopper cars--both truck and rail. If the materials are hazardous, the hopper cars must be the covered type, typically with bottom unloading ports.

Mechanical Conveyors. When a discharge pit is used for unloading, the material is conveyed to storage via one or more of three methods:

- Screw conveyor - a long pitch, steel helix flight mounted on a shaft supported by bearings within a U-shaped trough
- Belt conveyor - an endless neoprene-type belt moving horizontally or on an incline on a series of idlers
- Bucket elevator - a relatively simple unit for making vertical lifts. They should be totally enclosed to reduce fugitive dust emissions.

Pneumatic Conveyors. Pneumatic conveyors are commonly used to transfer dry granular or powdered materials, both vertically and horizontally, to plant areas that are hard to reach with mechanical conveyors. The properties of a material determine whether or not it can be successfully conveyed pneumatically. The material must pass through piping and auxiliary equipment without clogging, degradation, or segregation; it should not readily absorb moisture; and it must be readily disengaged from the conveying air. Materials from fine powders through 6-mm (1/4-inch) pellets can be handled.

3.1.2 Waste Storage

3.1.2.1 Municipal Solid Waste Storage

Storage Facilities. There are four general types of receiving/storage facilities for as-received refuse:

- Pit and Crane. This is commonly used in mass burning incineration systems. It has the advantage of ease of refuse handling and requires relatively little area. Its disadvantages include high construction cost, the need for a crane (which represents relatively high maintenance costs), difficulty in cleaning the pit, and difficulty in controlling fires in the pit. Refuse pits are normally sized for 3- or 4-day refuse storage.

- Tipping Floor. This is often used where front end processing is intended. Its advantages include the ability to clean the floor regularly and the ability to pre-sort the refuse to eliminate unprocessable and hazardous items. Also, refuse handling is accomplished with proven, reliable equipment (wheeled and skid loaders). Its disadvantages include the need for a large, unobstructed floor space and the large floor area required to provide more than a few hours of storage.

- Depressed Tipping Floor. This variation on the tipping floor concept uses an elevated area from which trucks dump onto a depressed flat floor; whee tracked vehicles manipulate the refuse in the depressed area. Advantages include separatio the vehicle unloading and refuse handling functions, increased storage capacity, refuse pre-sorting, and the possibility of refuse compaction by the tracked vehicles.

- Live Bottom. This type of storage facility consists of a large pit with either apron conveyors or hydraulic ram conveyors at its bottom for transfer and charging of refuse. Advantages include separation of unloading and refuse handling, automation of refuse handling, and greater refuse storage capacity in reduced space. Disadvantages include high construction cost and difficulty in separating unprocessable and/or hazardous items. Another problem with this system is that refuse may not feed itself onto the conveyor but may bridge above the conveyor surface creating severe operating problems.

3.1.2.2 Industrial Waste Storage

Waste Storage Area. Wastes received for incineration at a disposal facility are either incinerated directly (in some cases via pumping directly from the tank truck) or stored until they can be handled more conveniently. At some plants, waste blending occurs prior to storage. A waste sampling station must be included in the facility. Sampling of waste must be made prior to incineration. Analysis of samples can be onsite or at an offsite laboratory.

A hazardous waste storage area is normally designed to address three problem areas:

- Segregation of incompatible corrosive and reactive waste types

- Fire hazards due to flammable liquids and solids
- Toxic hazards to prevent human exposure during storage, transfer, and spill possibilities

3.1.2.3 Types of Storage

Liquid Storage. Liquid waste storage normally includes temporary holding tanks, batching tanks, main storage tanks, and transfer pumps. Holding tanks provide initial storage of wastes prior to final disposition of the material. Other tanks can store specific waste categories that have been analyzed and are ready for batching or incineration. Batching tanks are normally used to prepare an 8-hour shift of waste feed for the incinerator. Also, tanks may be needed to store supplemental fuel for incinerator firing.

Dikes must be provided around liquid waste storage tanks to contain any spills. A sump should be located within the diked area to collect spills and from which waste can be pumped. Another consideration in the design of a storage tank installation is control of release of volatile organic compounds from tank vents. Where storage tanks feed an incinerator, the vent can be directed to the incinerator for organic gas destruction. Any volatile organic discharge to the atmosphere, including tank breather vents, is subject to impingement point requirements of MOE regulation (see Chapter 2).

Installation and maintenance of aboveground tanks are less troublesome than for underground tanks. With underground storage, the functions of gauging, pumping, and leak detection become more difficult. Storage of hazardous wastes and liquids in underground tanks is discouraged because of the possibility of undetected leakage, whereas leakage can be visually determined in aboveground tanks.

Bulk Solids Storage. Solid hazardous waste materials that present a toxicity problem to plant personnel are normally stored in totally enclosed storage, such as single-outlet bins, multiple-outlet silos, and portable bins. These enclosures protect the material from exposure to the elements; they guard against dangers represented by possible explosive, flammable, ignitable, or corrosive properties of the waste material.

Industrial wastes are occasionally stored in piles (which are generally small). Many piles are in buildings or are maintained outside under cover on concrete pads. They are most frequently used to accumulate waste composed of a single, dry material.

Container Storage. Hazardous materials for incineration may arrive in small container form (e.g., 200-1/44-I gallon drums). The containers can be stored as received until used, provided they are in good condition and are not leaking.

The containers should be stored in a covered area off the ground in a manner that will preclude damage, weathering, and subsequent leakage. Storage pads of concrete or other relatively impervious materials should be used as a base to prevent leaching or percolation to groundwater.

3.1.3 Handling and Conveyor Systems

The following materials handling equipment is commonly used at incineration facilities.

Apron Conveyors. Apron conveyors consist of a series of jointed steel pans connected and driven by chains. They are used to convey unprocessed solid waste, generally as infeed to a primary shredder or trommel.

One type of apron conveyor that has proven successful in handling solid waste is the double-beaded, outboard roller type. If the feeding conveyor is wider than the subsequent (downstream) conveyor or equipment inlet port, "funneling" is very likely to occur, causing bridging and blockages. In addition, changes in direction should not be attempted when conveying unshredded solid waste.

Belt Conveyors. Belt conveyors are widely used to convey solid waste and various waste components after shredding. One exception is the shredder discharge conveyor itself; because material exits the shredder at a relatively high temperature (up to 100°C) and/or velocity, metal apron or vibrating conveyors are advisable.

Pneumatic Conveyors. Pneumatic conveying systems are available for the transport of the light fraction of shredded solid waste (RDF). These systems usually convey the material from an air classifier to storage. They consist of a blower, connecting ductwork, a cyclone for separating the light fraction from the conveying air, a fabric filter for final control, and a rotary airlock to discharge the light fraction from the cyclone. Pneumatic conveyors can also be used to move shredded material from storage to an incinerator.

Screw Conveyors. Screw conveyors are widely used to move granular solids and sludge waste. They can be run at an incline, although their maximum capacity rating is in the horizontal position. Screw conveyors longer than 3.6 m (12 ft) normally require intermediate support. If internal bearings are used, they should be positioned within the screw conveyor to minimize contact with the waste stream. Supporting an internal bearing from above is one such method. Likewise, end bearings should be mounted outboard of the conveyor to prevent contact with the waste stream.

3.1.4 Solid Waste Preparation

Trommel Screens. A trommel is a rotating perforated screen through which material is fed so that it can be classified by particle size. The inside face of the screen may have protruding knives or cutters that facilitate the breaking of plastic bags.

Shredding. Size reduction of incoming solid wastes is desirable to ease the handling of the wastes and to increase the burning efficiency of the incinerator. When wastes are received at a facility, they range in size from bulky, oversized materials to small particles. Shredding reduces the volume of material being handled, promotes more efficient handling of the wastes for other processes, and prepares the waste for air classification. Size reduction also increases the surface area of the wastes and promotes more efficient burning.

There are a number of different types of shredders commercially available. A rotary shear type shredder is a dual shaft unit utilizing counter-rotating cutters to tear and shear the waste. Flail mills are shredders which utilize a single rotor with various types of impactors (blades, chains, etc.) attached to the rotor to beat, cut, or thrash the waste.

Hammermills, both the horizontal shaft and vertical shaft types, are the most common equipment used for size reduction of municipal solid wastes. The horizontal hammermill has bottom grates and a horizontal rotating shaft. The grates control the discharge particle size.

With a vertical shaft hammermill, the input is fed at the top, and the rotating shaft is vertical. Size reduction is controlled by the spacing between the side walls and hammer on the rotary shaft. The mill is tapered so that the bottom is smaller than the top.

Both types of hammermills operate at approximately the same power efficiency; however, there are differences between the vertical and horizontal mill, as noted in Table 3-1.

Table 3-1
Comparison of Horizontal and Vertical Shaft Hammermills

Parameter	Horizontal Shaft	Vertical Shaft
Particle size control	Positive control; all material processed until small enough to pass grates	Not positive control; particle size controlled by feed size
Shredding of difficult materials	Subject to damage from oversized and difficult material; pre-sorting and/or top screens desirable	Less subject to damage; difficult items pass through machine; presorting not necessary
Wear rates	Hammer wear rates may be higher	Particle size gradually reduced so that wear on hammers is more evenly distributed
Motor Drive	Most manufacturers recommend direct drive	Most manufacturers recommend a gear or belt drive

The design of a shredder installation should include provisions for handling and storage of the wastes. Input is usually fed to the shredders by a conveyor and the output is brought to the next processing step by conveyor.

In addition to the feed and discharge systems, provisions for dust, explosion, and fire control are necessary at shredder installations. Water spray systems have been used successfully to control dust and fires at several installations; this method has the disadvantage of increasing refuse moisture content, which is counterproductive for incineration.

Another method to control dust and limit explosions is to continually exhaust the shredder housing with a pneumatic system. Such a system conveys the collected dust to a central point for storage and disposal.

Proprietary explosion suppression systems, such as the "Fenwal" system, flood the shredder housing with an inert gas in response to an extremely fast-acting pressure sensor that can react to certain types of explosions before pressures reach destructive levels.

Air Classification. Air classifiers, such as the one shown in Figure 3-1, are used to separate components in the solid waste stream. Shredded solid waste is separated into a "light" fraction (consisting primarily of paper, plastic, and other light organic material) and a "heavy" fraction (consisting of heavier organic and inorganic material).

Air classifiers generally operate by allowing the waste stream to fall through a rising current of air. Light particles with large surface areas are lifted by the air current; heavy and/or dense particles fall.

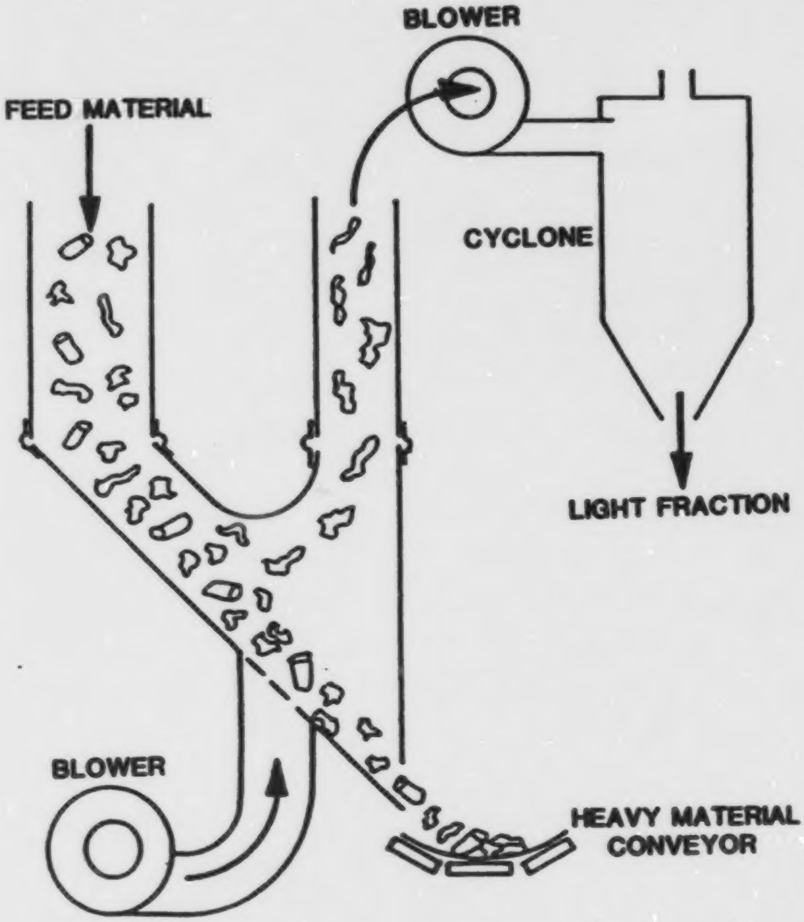

BLOWER
FEED MATERIAL
CYCLONE
LIGHT FRACTION
BLOWER
HEAVY MATERIAL CONVEYOR

Figure 3-1
AIR CLASSIFIER
(Triple/s)

A reasonable performance level for an air classifier is 85% recovery of light fraction with about 5% to 10% carry-over of heavy organics and inorganics.

3.2 SYSTEM SAFETY CONSIDERATIONS

3.2.1 Personnel Safety

The health and safety of the public and of plant employees should be considered of prime importance in any industrial installation design or operation. Equipment should be provided for worker protection, and procedures for worker protection should be developed.

3.2.2 Safety in Handling and Storage

3.2.2.1 Chemical-Spill Handling Plan

A chemical-spill handling plan should be provided for industrial incinerator installations. It should include:

- Monitoring requirements for possible spills of material
- Description of hazards associated with material that may be spilled
- Designation of the chain of command during a spill incident
- Specifications of equipment available for containment
- Disposition alternatives in response to a spill

3.2.2.2 Unloading and Transfer Safety and Emergency Provisions

Hazardous fluid unloading and transfer operations offer a high likelihood of accident, i.e., fire, spills, or worker exposure. Technical bulletins of the Chemical Manufacturers Association (CMA) and the American Petroleum Institute (API) provide guidance for the safe unloading of tank cars and tank trucks.

3.2.2.3 Storage Area Safety Provisions

Some provisions to protect personnel and the immediate environment from fire hazards and material spills that apply to the storage of large quantities of flammable liquids include:

- Provision of remotely operated valves to minimize flow of flammables
- Combustible gas monitors in the storage area
- Combustible gas monitors that automatically actuate a deluge system or safely shut down the system
- Drainage and collection ponds (equalization basins) to carry away liquid spills resulting from a fire incident

For the storage of drums, many safety precautions can be instituted for the protection of the operators who open and inspect drums prior to incineration. Safety features include:

- Explosion-proof electrical equipment
- Dry chemical and CO_2 fire extinguishers
- Special safety fork trucks with nonsparking forks
- Air-operated pumps
- Nonsparking tools
- Safety showers and eyewashes
- Safety glasses and face shields
- A general ventilation system with a moderate ventilation rate (minimum of three air volume changes per hour) and a high ventilation rate (minimum 12 air volume changes per hour) in the drum pumping room or area

For storage of bulk solids, evidence of spontaneous heating should be closely monitored. Heat-sensitive devices should be installed in silos and bins; they should be connected to a continuous temperature recorder at a central control board and arranged to sound an alarm if unsafe temperatures are generated.

3.2.2.4 Pump and Piping Safety Provisions

Hazardous and flammable-liquid pumping and piping systems should be equipped with emergency shutoffs to stop the flow of liquid in the event of fire or accidental escape of liquid or vapour.

3.2.3 Safety Combustion Control

Three supplemental fuels are in common use at incinerator facilities:

- Fuel oil (#2 grade normally used)--39 000 kJ/l (167,000 Btu/I gallon)
- Natural gas--37 000 kJ/m^3 (1,000 Btu/ft^3)
- Digester gas--15 000 to 22 000 kJ/m^3 (400 to 600 Btu/ft^3)

All new construction invariably uses automatic combustion control. As listed in Table 3-2, combustion control starts with the generation of a pilot flame, the proof of the pilot, the firing of the main fuel gun, and the proof of main flame.

Prior to any firing, a purge is initiated to preclude hide-out of combustible mixtures within the furnace that could cause explosion. Purging requires the placement of air-moving equipment (fans) in operation to produce an air wash, or purge, of the furnace for a minimum period of time.

The pilot is normally gas, which is electric spark ignited. It may be on only for that period of time required to light the main burner and prove combustion.

3.2.4 Noise Control

In planning, construction, and operation of an incineration facility the proponent should comply with the pro-

Table 3-2
Combustion Control Requirements for Different Burner Systems

	Underwriters Laboratories 296 (Oil)	Underwriters Laboratories 795 (Gas)	Factory Mutual Auto Lighted Boilers	Industrial Risk Insurers Automatic Single Burner	National Fire Protection Association 85
Scope	Over 400 000 kJ/h	Over 400 000 kJ/h	3.5×10^6 kJ/h Oil 1.8×10^6 kJ/h Gas	Over 400 000 kJ/h	Over 12.5×10^6 kJ/h
Prepurge	No Mention	• 4 air changes at 1/3 air flow minimum or • 30 s @ highfire air flow rate • 90 s @ 1/3 highfire air flow rate • Atmospheric 90 s without automatic shutters; no prepurge required	• 4 air changes @ 50% average air flow superised • Automatic dampers which close during down time on natural draft boiler must be opened 90 s prior to each start	4 air changes @ 60% min. air flow supervised	8 air changes reaching not less than 70% air flow supervised
Pilot Proving	• Required over 75.7 L/h starting rate • 15 s	• Under 2.5×10^6 kJ/h - 15 s • Over 2.5×10^6 kJ/h - 10 s	10 s	10 s max.	10 s
Main Flame Trial for Ignition (Oil)	• Spark or unproved pilot 11.4 L/h max. 90S 11.4 to 26.5 L/h -30S 26.5 to 75.7 L/h -15S • Over 11.4 L/h with proved pilot Distillate -10S Residual -15S	Not Applicable	• No. 2 & 4 oil - 10 s • No. 5 & 6 oil - 15 s	• No. 2 & 4 oils - 10 s • No. 5 & 6 oils - 15 s * UL timings take precedence	• No. 2 & 4 oils - 10 s • No. 5 & 6 oils - 15 s
Main Flame Trial for Ignition (Gas)	Not Applicable	• Under 2.5×10^6 kJ/h - 15 s • Over 2.5×10^6 kJ/h - 10 s	10 s	15 s (published) UL takes precedence	10 s
Flame Failure Response Time	4 s max.	4 s max.	4 s max.	4 s max.	4 s max.
Interlocks Required	Shutdown on loss of atomizing means	Over 2.5×10^6 kJ/h non-recycling high and low gas pressure switches	• Over 12.5×10^6 kJ/h prove fuel valve closed prior and during purge • Low fire start • Low oil temp. NON-RECYCLING • High and low gas pressure • Min. air flow • Atomizing medium	• High and low oil temp. • Low fire start NON-RECYCLING • Supervised • Atomizing medium • High and low gas pressure • Min. combination air • Rotary burner power outage to motor • Low oil pressure	• Low fire start • Manual start from cold start • Prove safety shutoff valve closed NON-RECYCLING • Loss of combustion control system activating energy • Low oil temp. and pressure • Atomizing medium • Minimum air flow

* Underwriters Laboratories

visions of the "Model Municipal Noise Control By-Law, Aug. 1978", Technical Publication NPC-133, guidelines on information required from the assessment of planned stationary sources of sound, Technical Publication NPC-105, stationary sources, and Technical Publication 132, guidelines for noise control in rural areas.

Noises generated within an incineration facility are generally those resulting from the movement of air or gas. Fans and blowers will create the greatest noise levels, and of secondary concern is the noise generated by passage through ducts, flues, and nozzles.

Noise exposure to operators, other personnel within the facility limits, and the general environment must be considered as part of the facility design.

Where a worker is likely to be exposed to a sound (noise) level of 90 decibels or greater, measures shall be taken to reduce the sound level below 90 decibels. If such measures are not practical, the duration of exposure shall not exceed that indicated in Column 2 of Table 3-3 or the worker shall wear hearing protection. A worker shall always wear hearing protection when the sound level is or is expected to be 115 decibels or greater.

Clearly visible warning signs shall be posted to the approaches to an area where the sound level is more than 90 decibels as indicated in the Occupational Health and Safety Act and Regulations for Industrial Establishments, Chapter 321 of the Revised Statutes of Ontario, Regulation 692 and Regulation 714/82. The types of hearing protection devices used shall also be provided in accordance with these regulations.

Table 3-3
Noise Exposure Levels

Column 1 Sound Level in Decibels	Column 2 Duration - Hours per 24-hour Day
90	8
92	6
95	4
97	3
100	2
102	1?
105	1
110	?
115	? or less
Over 115	No exposure

Note: "Decibel" means decibel measured on a type 2 sound level meter conforming to the standard Z107.1 of the Canadian Standards Association operating on the A-weighing network with slow meter response.

3.3 RECORDKEEPING

Records of routine operation, receipt of materials, maintenance of specific equipment, unique operations, and general inspections of the facility are used to:

- Assess service levels and operating factors
- Institute preventive maintenance programs
- Train operating and maintenance personnel
- Screen delivered materials for acceptable form and packaging
- Respond to special requests for service
- Demonstrate compliance with health, safety, and environmental standards

These records can be kept in the form of log sheets, log books, receipts, bills, purchase orders, certificates, and card files. There is also a considerable number of choices for automated recordkeeping tools. These include bar code generators, data loggers, microprocessor controller/recorders, and computers.

Chapter 4

INCINERATOR DESIGN AND OPERATION

4.1 INTRODUCTION

This chapter describes the design constraints and operating parameters of incinerators and incineration systems. Material and energy balances are presented, techniques for evaluating incinerator designs are developed, and operating parameters are discussed. It provides the user with not only a guide to current technology, but relatively easy-to-use methods of determining incinerator parameters.

4.1.1 Determining Waste Properties

Wastes are, by definition, non-uniform in quality. In order to proceed with equipment selection and design, however, waste characteristics must be determined or developed. Determination of waste properties can be made by referring to tabular data of materials, measurement of material properties, or, when waste analysis can be established, by calculating these properties. The determination of waste properties is of particular importance in addressing the Range of Operation aspects of Policy 01-01 (see Appendix B).

Incinerators should not be rated (specified) on the basis of performance on Type 0 or Type 1 waste. They should be rated and tested on the specific waste stream (e.g. refuse, Type 2, or Pathological, Type 4, wastes). If it can be clearly demonstrated that Type 2 or Type 4 wastes will never be fired in the incinerator, a detailed analysis (proximate and ultimate analyses) of the waste stream should be defined as the basis of performance of the incinerator.

4.1.1.1 Waste Characteristics

A waste material considered as an incineration candidate will normally have a combustible component, a non-combustible component, and may contain moisture. Generally, heating value is stated relative to the waste combustible component. Heating value can be noted as a gross number applied to the total waste quantity, but the combustible, non-combustible, and moisture components must be identified in order to determine the heat content of a material.

4.1.1.2 Tabular Values

Table 4-1 lists properties of various waste materials relative to incineration. Included are heating value, density, and typical ash and moisture components. Table 4-2 identifies common waste designations. Municipal solid waste composition in various locations is listed in Table 4-3 and Table 4-4 lists combustion characteristics of those wastes generated in the Hamilton area.

4.1.1.3 Laboratory Analyses

Proximate analysis and ultimate analysis are two widely accepted techniques used for the measurement of waste parameters.

Proximate Analysis. Proximate analysis as per ASTM D 3172 is a relatively quick and inexpensive laboratory determination of the percentages of moisture, volatile matter, fixed carbon, and ash. The analytic procedure is as follows:

Table 4-1
Characteristics of Selected Materials

Waste	Heating value as fired kJ/kg	Density kg/m^3	Content Weight Ash	Percent Moisture
Newspaper	18 600	110	1.5	6.0
Brown paper	16 900	110	1.0	6.0
Magazines	12 200	560	22.5	5.0
Corrugated paper	16 400	110	5.0	5.0
Plastic coated paper	17 100	110	2.6	5.0
Coated milk cartons	26 400	80	1.0	3.5
Citrus rinds	3 950	640	0.75	75.0
Shoe leather	16 800	320	21.0	7.5
Butyl sole composition	25 400	400	30.0	1.0
Polyethylene	46 500	960	0.0	0.0
Polyurethane (foamed)	30 200	32	0.0	0.0
Latex	23 000	720	0.0	0.0
Rubber waste	23 300	1 500	25.0	0.0
Wax (paraffin)	43 300	890	0.0	0.0
1/2 tar-2/3 paper	26 700	140	3.0	1.0
Tar or asphalt	39 500	960	1.0	0.0
1/2 tar-2/3 paper	25 600	240	2.0	1.0
Wood sawdust (pine)	22 300	180	3.0	10.0
Wood sawdust	19 000	180	3.0	10.0
Wood bark (fir)	22 100	260	3.0	10.0
Wood bark	19 200	260	3.0	10.0
Corn cobs	18 600	200	3.0	5.0
Rags (silk or wool)	21 000	200	2.0	5.0
Rags (linen or cotton)	16 700	200	2.0	5.0
Animal fats	39 500	880	--	0.0
Cotton seed hulls	20 000	440	2.0	10.0
Coffee grounds	23 200	440	2.0	20.0
Linoleum scraps	25 600	1 400	25.0	1.0

The above chart shows the various heating values of materials commonly encountered in incinerator designs. The values given are approximate and may vary based on their exact characteristics or moisture content. The heating value is the higher heating value.

Table 4-2
Ranges of Heating Values and Other Physical Characteristics for The Types of Wastes Defined in Standard CSA Z103-1976

Type	Description	Moisture, Weight Percent Wet Basis	HHV kJ/kg Wet Basis	HHV kJ/kg Dry Basis	Bulk Density kg/m³ as Fired
A	Cellulosic solids with up to 15% moisture	0-15	7900-27900	9300-27900	80-961
B	Cellulosic solids with 10-50% moisture	10-50	4600-20900	9300-27900	48-961
C	Cellulosic solids with over 40% moisture	40-80	2300-16700	9300-27900	48-993
D	Plastics and asphaltic solids, non-halogenated	0-30	17400-46400	18600-46400	32-1298
E	Plastics and asphaltic solids, halogenated	0-30	15800-30600	20400-30600	80-2307
F	Rubber	0-15	20200-36200	23600-36200	144-2003
G	Animal materials	5-85	2300-22000	23200	16-1298
H	Animal and human wastes	30-85	2300-20200	15600-28800	481-1282
I	Non-combustible solids	0-15	0	0	80-4486
J	Pathological materials	10-30	10400-18800	11600-20900	80-1041
K	Pathological remains	85	2300	23200	801-1202
L	Cadavers, coffin encased	40	13700	24100	641-1282
M	Organic liquids with under 30% water	0-30	70-39500	70-39500	721-1202
N	Organic liquids with over 30% water	30-80	700-27900	700-39500	641-1121
O	Fumes	0-80	1900-141600	9300-141600	0.64-5.45
P	Particulates, gas-borne	0-20	0-1200	0-1200	0.64-1.60
Q	Radioactive materials	0-50	0-46400	0-46400	32.0-8010
R	Special wastes	0-80	0-41800	0-41800	32-4486

Note: This table is from Incinerator Performance, CSA Standard Z103-1976

Table 4-3
Composition of Municipal Solid Waste From Selected Locations
(percent wet weight)

Component	U.S. National Average (1)	Ontario Average (2)	Hamilton, Ontario (3)	Canada National Average (2)
Combustibles				
Paper	33.5	38.88	35.0	36.5
Food Waste	17.0	30.55	14.0	27.6
Yard Waste	17.5	3.30	13.0	6.1
Plastics	3.6	4.86	5.9**	5.2**
Rubber, Leather	2.6	-	-	-
Textiles	2.0	3.55*	2.7	4.3
Wood	3.2	3.36	5.2	4.2
Miscellaneous Organics	-	0.31	-	1.1
Total	79.4	84.81	75.8	85.0
Noncombustibles				
Glass, Ceramics	9.9	8.27	8.2	8.4
Metals	9.2	6.15	-	6.6
- ferrous	(8.0)	5.34	7.7	
- aluminum	(0.9)	(0.77)	-	
- other	(0.3)	(0.04)	0.7	
Fines	-	0.77	5.7	
Miscellaneous Organics	1.5	-	1.9	
Total	20.6	15.19	24.2	15.0

* includes rubber and leather
** includes rubber

References:

(1) Tenth Annual Report of the Council of Environmental Quality, Municipal Solid Waste, December 1979.

(2) Bird and Hale Ltd., Clarke Derszko and Associates Ltd., L.S. Love and Associates Ltd., Municipal Refuse Statistics for Canadian Communities of Over 10,000 (1976-1977), prepared for Environmental Protection Service, Environment Canada, 1979.

(3) Walls, T.B., Energy Recovery From Mass Burning of Municipal Solid Wastes, proceedings from Resource Recovery from Solid Wastes Conference, Miami Beach, Florida, May 1982.

Table 4-4
Combustion Characteristics of Municipal Solid Waste Generated in the Hamilton Area

Ultimate Analysis	Percent by Weight
Carbon	18.5
Hydrogen	2.9
Nitrogen	0.5
Oxygen	23.0
Sulphur	0.1
Moisture	25.0
Ash	30.0
Total	100.0

Higher Heating Value (kJ/kg)	11,165

Proximate Analysis	Percent by Weight
Volatile Matter	38.5
Fixed Carbon	6.5
Moisture	25.0
Ash	30.0
Total	100.0

Reference: Walls, T.B., Energy Recovery From Mass Burning of Municipal Solid Wastes

- Heat a sample for one hour at 105°C to 110°C (221°F to 230°F). Report the weight loss fraction as percent moisture.

- Raise the temperature of the dried sample in a covered crucible to 725°C (1337°F) and hold it at this temperature for 7 minutes. Report the sample weight loss fraction as volatile matter percentage.

- Ignite the remaining sample in an open crucible at 950°C (1742°F) and allow it to burn to a constant weight. Report the sample weight loss as percent fixed carbon.

The sample residue is to be reported as percent ash. The sum of moisture, volatiles, fixed carbon, and ash should equal 100%.

Ultimate Analysis. Ultimate analysis is a standard procedure used for a determination of the quantities of elemental components present in a sample (ASTM D 3176). It is required in order to determine the products of combustion of a material, its combustion air requirement, and the nature of the off-gas or combustion products.

In this procedure the following element percentages are normally determined:

- Carbon
- Hydrogen
- Sulphur
- Oxygen
- Nitrogen
- Halogens (chlorine, fluorine, etc.)
- Heavy metals (mercury, lead, etc.)
- Other elements that can affect the combustion process

In addition to these components, analyses may be performed under the heading of ultimate analysis for the presence of certain compounds that may be in the waste, such as chlorobenzene, chlorophenols, PCBs (polychlorinated biphenyls), dioxins, etc.

It must be recognized that wastes are often extremely heterogeneous in nature. The proper selection of a representative sample is at least as important as performing the test itself. Most commonly used methods involve dumping a truckload of material in an enclosed area, and then reducing the truckload to an approximately 100-kg sample by a process of repeatedly quartering the waste and discarding three-fourths. Generally, landfill equipment (a bulldozer or wheeled loader) is used for quartering. Alternative methods include selecting a random sample using a grid method, and treating the entire truckload as the sample.

After sample selection is completed, the material can be sorted into standard components (food wastes, paper, cardboard, plastics, textiles, rubber, leather, garden trimmings, wood, glass, non-ferrous metals, ferrous metals, dirt, ashes, etc.) so that each component can be analyzed.

4.1.1.4 Calculated Values

The approximate waste heating value can be calculated when the elemental conditions of the waste can be determined. If the fractions of carbon, hydrogen, oxygen, and sulphur can be determined, the DuLong equation can be used to approximate heating value. This equation is as follows:

$$Q = 33,829\ C + 144,277\ (H_2 - 0.125\ O_2) + 9420\ S$$

where Q is in kJ/kg and C, H_2, O_2, and S are the weight fractions of carbon, hydrogen, oxygen, and sulphur present. The weight fractions should add to 100% unless an inert material such as nitrogen is present. With the presence of nitrogen, for instance, the weight fraction (%) of C, H_2, O_2, and S will total 100% less the fraction of nitrogen present.

4.1.2 Waste Destruction Guideline

For domestic, biomedical, commercial and non-hazardous industrial waste, off-gases should pass through a zone of 1000°C (1832°F) minimum temperature (minimum) and should have a residence time within that zone of at least one second. (See Policy 01-01, Appendix B). Temperatures in excess of 1100°C (2012°F) should be avoided to minimize the potential for slagging. Oxygen measured at the exhaust of the incinerator should be a minimum of 6% (in situ, wet gas, by volume).

Incinerators should be operated at negative pressure to avoid the escape of incomplete combustion products. If provided, any emergency exhaust system should be located downstream of the afterburner.

Test burns should be performed to determine the appropriate temperature and residence time for industrial waste streams. In the absence of such data and as a first approximation when burning non-halogenated, non-polynuclear waste, a temperature of 1000°C (1832°F) should be maintained for a period of time of at least 2 seconds and with an oxygen content (as measured immediately downstream of the furnace section) of 3% minimum (dry volume). For polynuclear and for halogenated wastes, the minimum temperature should be 1200°C (2191°F) with a residence time of 2 seconds and an oxygen content of the flue gas of 3% (dry volume) minimum. For non-combustible wastes (such as soils) contaminated with organics, the minimum off-gas temperature should be no less than 700°C (1292°F) and the minimum ash (residue) discharge temperature should be no less than 550°C (1022°F) at the outlet of the incinerator chamber where these materials are being fired. Note that these are guidelines and that the required temperature, residence time, and oxygen fraction must be determined after an overall design and process review, which should include performance of test burns.

4.1.3 Design Calculations

Important parameters of incinerator design and operation include the temperature that waste will burn at without the addition of supplemental fuel, whether supplemental fuel is required for waste destruction, the quantities of air required, and the amount of flue gas generated from the burning waste.

4.1.3.1 Adiabatic Temperature

The temperature at which a waste will burn without considering process losses is its adiabatic temperature. These process losses would include radiation losses from the furnace walls and heat lost in the ash discharge. The adiabatic temperature is a function of the waste combustible heating value, waste combustible content, moisture content, and excess air requirement. As a first-order approximation of adiabatic temperature for any combustible material, the as-received waste heating value can be used. Figure 4-1 is a graph of adiabatic temperature versus gross (as-received or as-fired) heating value for various values of excess air. It is applicable for any material,

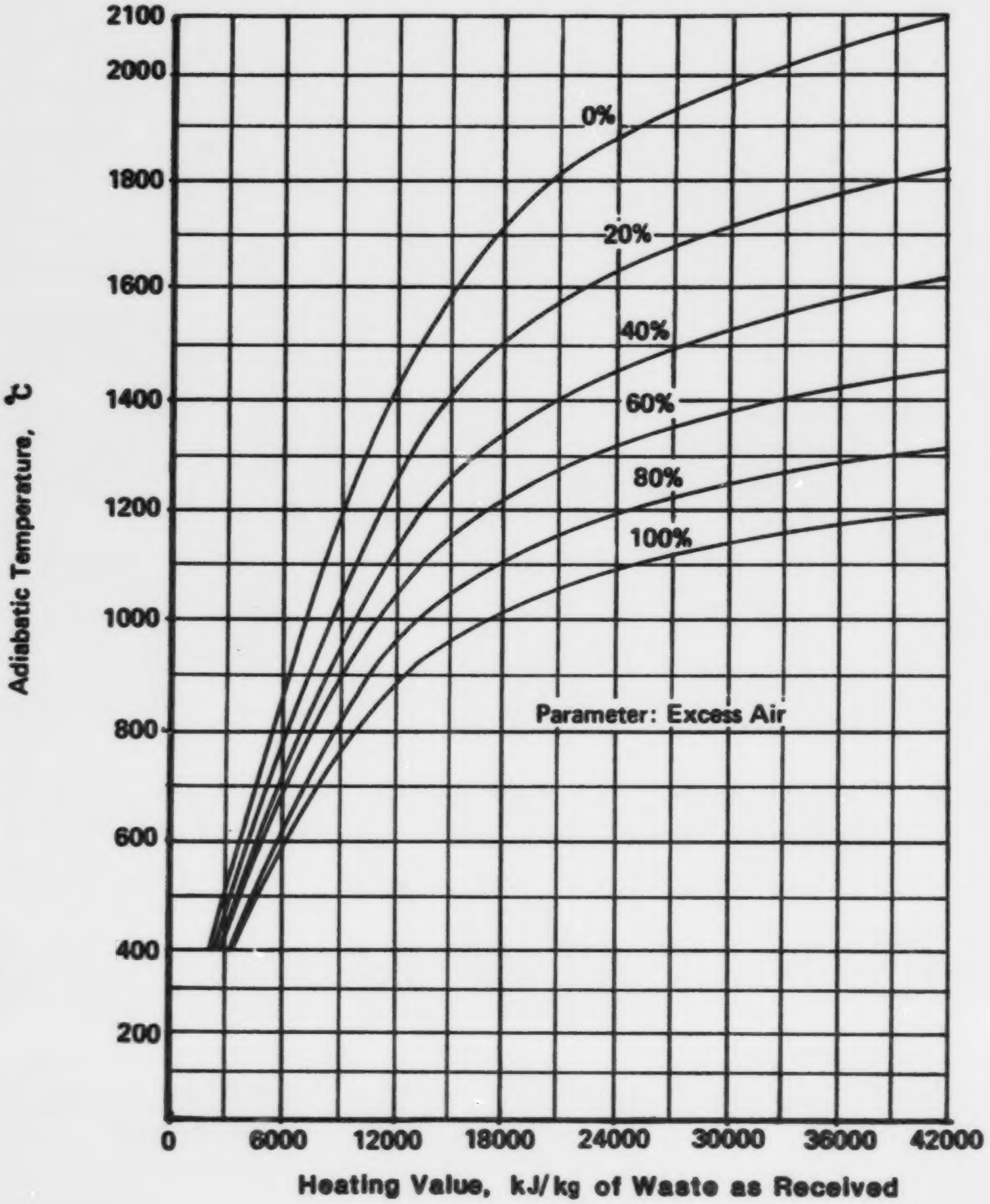


Figure 4-1
ADIABATIC TEMPERATURE VS. EXCESS AIR

liquid, solid, or gas. Excess air values for typical furnaces are given in Table 4-5.

Table 4-5
Typical Excess Air Values

Incinerator Type	Excess Air Range
Fluid bed	40% - 60%
Gaseous waste	10% - 15%
Liquid waste	15% - 30%
Multiple chamber (Retort, in-line)	100% - 200%
Multiple hearth	100% - 125%
Rotary kiln	100%
Waterwall	65% - 100%

Using Figure 4-1, for example, a waste with an as-received heating value of 8000 kJ/kg (3440 Btu/lb) is burned in a fluid bed incinerator using 60% excess air. As an example, combustion of this waste is assumed to require 1000°C (1830°F) for effective destruction. From the graph, the adiabatic temperature is approximately 900°C (1650°F), and therefore, supplemental fuel is required to achieve a combustion temperature of 1000°C (1830°F).

This graph gives an approximate temperature of combustion and provides an indication of whether or not to proceed with a detailed analysis of incinerator parameters.

4.1.3.2 Incinerator Analysis

There are a number of incinerator parameters that are normally of interest, including the following:

- Furnace temperature
- Supplemental fuel requirement

- Combustion air requirement
- Flue gas discharge quantity
- Residence time
- Turbulence/mixing

From these parameters, sizes of equipment associated with the incinerator system can be calculated.

Table 4-6 represents a step-by-step method of analysis for an incinerator system. It is a simplified mass and heat balance. The feed quantity, moisture fraction, noncombustible fraction, and combustible heating value must be known. An excess air and humidity figure must be selected as well as a reasonable radiation figure (from 1% to 5% of the total heat release) and an ash heat content (ash will normally represent a heat loss in the range of 160 to 340 kJ/kg [69 to 146 Btu/lb] of ash). The required gas temperature for destruction of the waste stream must be selected.

This analysis is a detailed heat balance based on the principle that the total heat leaving (exiting) a system is equal to the heat entering that system. Heat entering a system includes the potential heat release of a waste, and/or fuel, that is fired within that system.

One important assumption made in this analysis is that flue gas from an incinerator is composed of moisture plus dry air. Actual incinerator off-gas contains more carbon dioxide and less oxygen than is found in air. The assumption that dry flue gas has the properties of air, however, greatly simplifies calculations while introducing a relatively small error (less than 3%) in calculated temperatures and heat requirements.

Table 4-6
Incinerator Analysis

1. Feed quantity (as-received)	______	Given
2. Moisture fraction	______	Given
3. Moisture quantity (kg/h)	______	1 x 2
4. Solids quantity (kg/h)	______	1 - 3
5. Noncombustible fraction	______	Given
6. Noncombustible quantity (kg/h)	______	4 x 5
7. Combustible quantity (kg/h)	______	4 - 6
8. Heating value (kJ/kg combustible)	______	Given
9. Total heat generated (kJ/h)	______	7 x 8
10. Stoichiometric air ratio (kg/kg combustible)	______	Figure 4-2a
11. Stoichiometric air (kg/h)	______	7 x 10
12. Excess air fraction	______	Given
13. Excess air (kg/h)	______	11 x 12
14. Total air required (kg/h)	______	11 + 13
15. Moisture generated (kg/kg combustible)	______	Figure 4-2b
16. Moisture generated (kg/h)	______	7 x 15
17. Humidity (kg/kg dry air)	______	Given
18. Humidity (kg/h)	______	14 x 17
19. Total moisture (kg/h)	______	3 + 16 + 18
20. Dry flue gas (kg/h)	______	7 + 14 - 16
21. Radiation heat loss (kJ/h)	______	Given
22. Ash heating value (kJ/kg)	______	Given
23. Ash heat loss (kJ/h)	______	6 x 22
24. Humidity correction (kJ/h)	______	18 x 2186
25. Miscellaneous heat loss (kJ/h)	______	Given
26. Heat in flue gas (kJ/h)	______	9 - 21 - 23 + 24 - 25
27. Flue gas temperature (°C)	______	19, 20, 26
28. Required gas temperature (°C)	______	Given
29. Required flue gas heat content (kJ/h)	______	19, 20, 28
30. Heat required (kJ/h)	______	29 - 26
31. Fuel excess air	______	Given
32. Fuel required (l or m^3/h)	______	Figure 4-3a or 4-3b,30,31
33. Air for fuel (kg air/l or m^3)	______	Table 4-5,31
34. Air required (kg/h)	______	33 x 32
35. Moisture from fuel (kg/l or m^3)	______	Table 4-5, 31
36. Moisture generated (kg/h)	______	35 x 32
37. Dry gas from fuel (kg/l or m^3)	______	Table 4-5, 31
38. Dry gas generated (kg/h)	______	37 x 32
39. Total dry gas flow (kg/h)	______	38 + 20
40. Total moisture flow (kg/h)	______	35 + 19
41. Total heat at exit (kJ/h) gross htg value)	______	26 + 32 x (Fuel)

Air quantities required to support combustion must be determined to perform these calculations. If the exact waste composition is known, the air requirements can be determined by calculation from the equilibrium equations, as follows:

For combustion of carbon,

$$C + O_2 \rightarrow CO_2$$

For combustion of hydrogen,

$$H_2 + ?O_2 \rightarrow H_2O$$

For sulphur,

$$S + O_2 \rightarrow SO_2$$

With each kg of oxygen, nitrogen is present in air,

1 kg air = 0.2315 kg O_2 + 0.7685 kg N_2
1 kg oxygen carries 3.3197 kg nitrogen from air

Usually there is some uncertainty about the range of waste composition and properties. The curves in Figures 4-2 and 4-3 were generated based on the DuLong equation (see Section 4.1.1.4). Using this equation, a relationship between gas composition and heating value was established and plotted (Figure 4-2 relates the stoichiometric air requirements to heating value; Figure 4-3 relates moisture produced from combustion to heating value). These values are approximate, recognizing that the DuLong equation represents only an estimate of heating value.

Figures 4-4 and 4-5 and Table 4-7 indicate the net heat available from supplemental fuel combustion in an inciner-

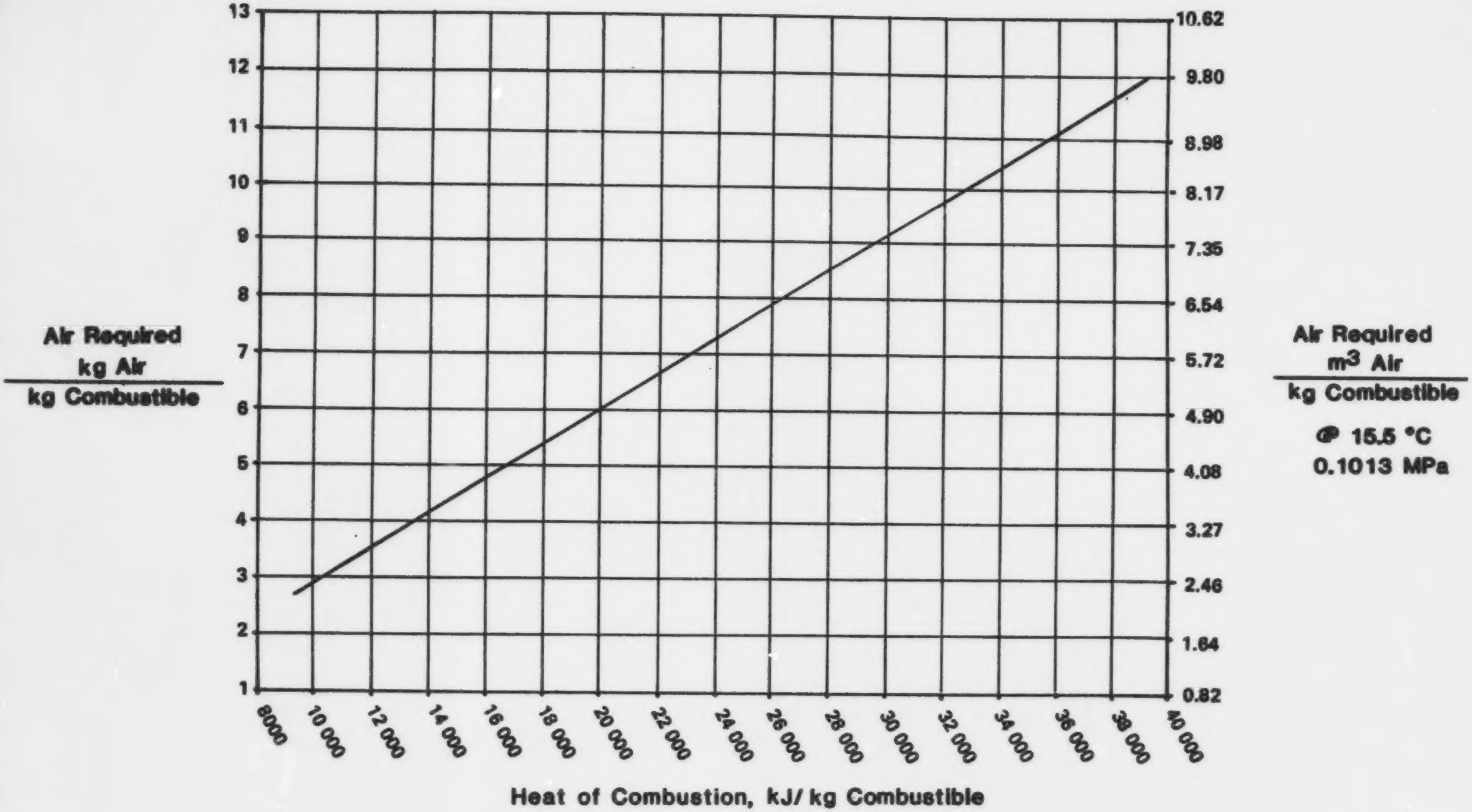


Figure 4-2

AIR REQUIRED, STOICHIOMETRIC COMBUSTION

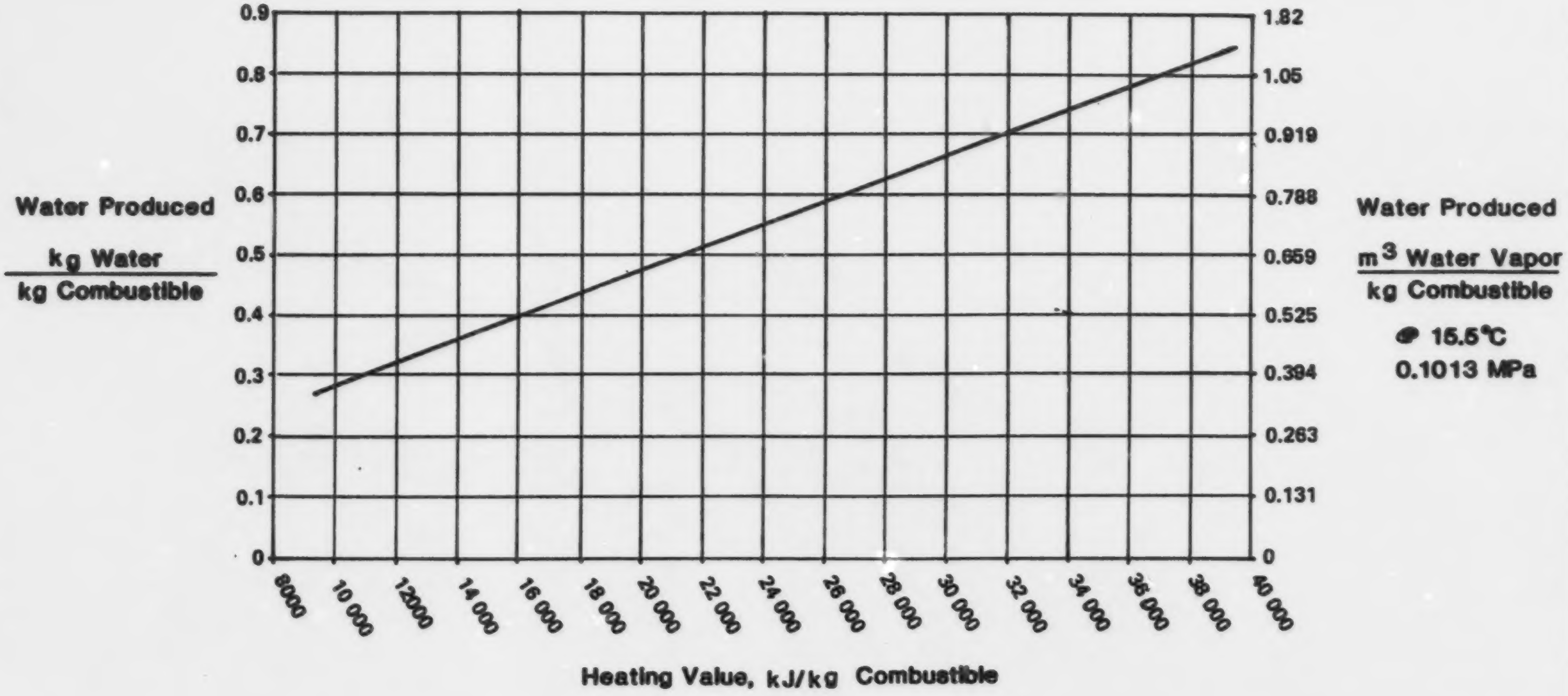


Figure 4-3
WATER PRODUCED FROM COMBUSTION
(Zero Humidity)

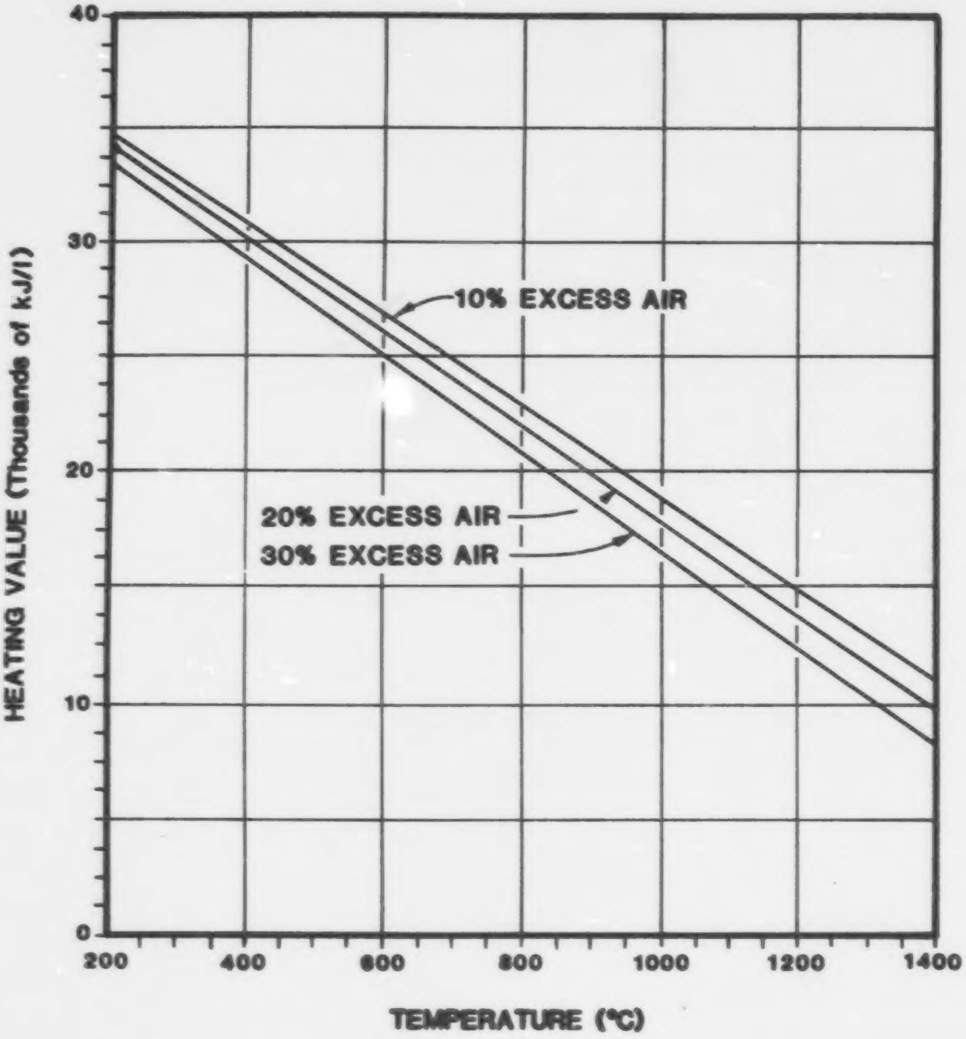


Figure 4-4
NET HEAT AVAILABLE, No. 2 FUEL OIL
FOR 10, 20, 30% EXCESS AIR
AS A FUNCTION OF TEMPERATURE

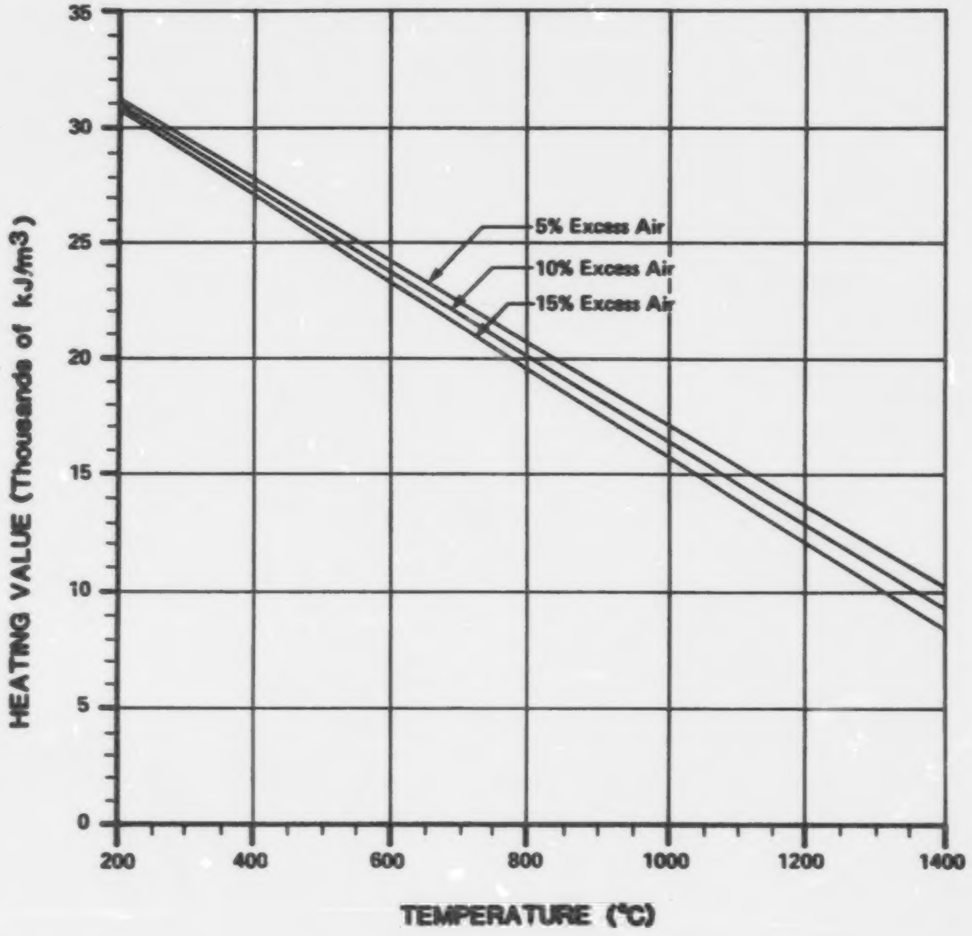


Figure 4-5

NET HEAT AVAILABLE, NATURAL GAS FOR 5, 10, 15% EXCESS AIR AS A FUNCTION OF TEMPERATURE

Table 4-7
Supplemental Fuel Combustion

No. 2 Fuel Oil, Heat Content of 39 100 kJ/l, Density of 0.91 kg/l

	Total Air		
Percent Excess Air	10	20	30
kg air/l	13.78	15.03	16.29
kg dry gas/l*	13.84	15.09	16.34
kg water/l*	1.04	1.05	1.07

Natural Gas, Heat Content of 37 256 kJ/m^3, Density of 0.80 kg/m^3

	Total Air		
Percent Excess Air	5	10	15
kg air/cubic metre gas	12.09	12.66	13.24
kg dry gas/cubic metre gas*	11.40	11.97	12.55
kg water/cubic metre gas*	1.65	1.65	1.66

* Products of Combustion

ation process. As the temperature of the process (the incinerator exit temperature) increases, the heat required to raise the temperature of the products of combustion of supplemental fuel to the incinerator exit temperature increases. The heat available for process heating (the net heating value) is the heat of combustion of the fuel less heat lost to products of combustion of supplemental fuel. The available heat, therefore, decreases with increasing temperature, as shown in Figures 4-4 and 4-5 for No. 2 fuel oil and natural gas. This net heating value must be used in incinerator calculations.

A detailed example of an analysis of an incineration system is included in Appendix C.

4.1.4 System Design Features

After design calculations have been performed, system design can proceed. System design includes incinerator chamber sizing, fan sizing, flue sizing, etc.

4.1.4.1 Duct Sizing

Ducts convey air and are normally sized to provide no more than 12 m/s (40 ft/s) air flow velocity. Higher velocities result in excessive noise and excessive pressure drop.

4.1.4.2 Flue Sizing

Flues carry gaseous products of combustion (flue gas) from the incinerator. They generally are sized to allow no more than 9 m/s (30 ft/s) gas flow. At higher velocities the particulate normally present in the exhaust will tend to accelerate flue erosion.

Table 4-8
Typical Heat Release Rates

Incinerator	Heat Release	
* Fluid Bed	350 000 - 500 000 $\frac{kJ}{m^2\text{-}h}$	bed area
Multiple Chamber	300 000 - 400 000 $\frac{kJ}{m^3\text{-}h}$	
Multiple Hearth	300 000 - 400 000 $\frac{kJ}{m^3\text{-}h}$	
* Multiple Hearth	250 000 - 350 000 $\frac{kJ}{m^2\text{-}h}$	hearth area
Gaseous Waste Incinerator	3 000 000 - 10 000 000 $\frac{kJ}{m^3\text{-}h}$	
Liquid Waste Incinerator	1 000 000 - 3 000 000 $\frac{kJ}{m^3\text{-}h}$	
Rotary Kiln	500 000 - 1 500 000 $\frac{kJ}{m^3\text{-}h}$	
* Solid Waste Grate	150 000 - 300 000 $\frac{kJ}{m^2\text{-}h}$	grate area

* These heat release values are based on surface area, not volume

4.1.4.3 Chamber Sizing

Chamber sizing is based on heat release. There is a limit to the quantity of heat that can be released in a particular furnace chamber. Heat release is that amount of heat generated when combustible material burns. When combustible gases burn or when liquids burn in suspension, the volume of the furnace chamber will limit the total amount of heat released within that chamber. The furnace volume must be large enough to allow release of the heat generated by the anticipated waste and the supplemental fuel.

When a solid or sludge waste is fired, the heat release (heat generated per chamber volume or hearth area per hour) of that waste is characterized by the area of the surface on which it is placed, i.e., the hearth or grate.

Table 4-8 lists typical heat release values for some common incinerator systems. The calculated heat release is determined by dividing the value in step 41 of Table 4-4 (which includes heat released from the waste plus the heat release from supplemental fuel) by the hearth or grate area (or chamber volume).

Heat release rates for multiple chamber incinerators and starved air units have been considered in developing the design data on Figures 4-11, 4-12, and 4-14.

As an example of the use of this information, a reasonable size of a rotary kiln used for destruction of 2000 kg/h (4410 lb/hr) waste with a heat content of 17 000 kJ/kg (7309 Btu/lb) is calculated as follows:

$$2000\ \frac{\text{kg}}{\text{h}} \times 17\ 000\ \frac{\text{kJ}}{\text{kg}} = 34\ 000\ 000\ \frac{\text{kJ}}{\text{h}}$$

Using a 1 000 000 $\frac{\text{kJ}}{\text{m}^3\text{-h}}$ heat release rate,

$$34\ 000\ 000\ \frac{\text{kJ}}{\text{h}} \div 1\ 000\ 000\ \frac{\text{kJ}}{\text{m}^3\text{-h}} = 34\ \text{m}^2$$

(1200 ft^3) volume

For a kiln with a 2.5-m internal diameter (Unit Cross Sectional Area = 4.91 m^2), the required length is

$$\frac{34\ \text{m}^3}{4.91\ \text{m}^2} = 6.93\ \text{m}\ (22.7\ \text{ft})$$

The kiln for this application would have an internal diameter of 2.5 m (8.2 ft) and a length of 7.0 m (23 ft).

4.1.4.4 Turbulence and Mixing

In order to achieve high combustion efficienices in incinerators, it is particularly important to achieve good mixing between the primary combustion products (primarily CO and organics) and a stoichiometric excess secondary combustion air. This mixing can be promoted by a range of physical parameters as well as by promoting highly turbulent flow of the gases. Physical parameters which are used to promote mixing include:

- location and direction of secondary air jets;
- volume and pressure of secondary air addition;
- changes in flow direction(s);
- other baffling techniques;

As well as the provision of overall mixing using the above methods, the eddies formed by turbulent flow promote local mixing of the combustible gases and air. The degree of

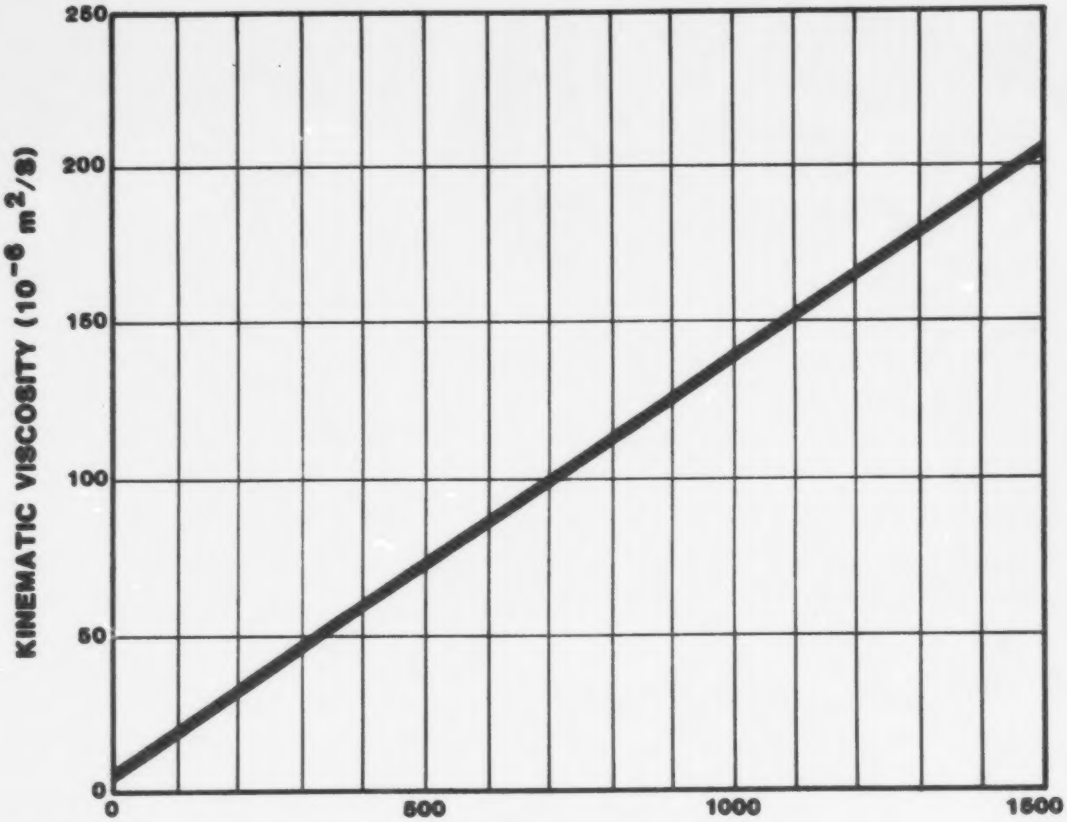


Figure 4-6
KINEMATIC VISCOSITY OF AIR vs TEMPERATURE

turbulence is typically assessed by use of the Reynolds Number, N_{RE}:

$$N_{RE} = \frac{VD}{K}$$

where V = average velocity, m/s
D = diameter (or equivalent diameter) of flow stream, m
K = kinematic viscosity, m^2/s, Figure 4-6

When the Reynolds number is below 2300 (defined as the critical Reynolds number), flow is generally considered laminar with no significant turbulence.

As a guide, the gas flow within an incinerator chamber or flue should have a Reynolds number well above 10,000. As an example of this calculation, assume a flue exiting a furnace has an internal diameter of 2 m (6.6 ft). The gas flow is at a temperature of 1000°C (1832°F), and is at a velocity of 10 m/s (33 ft/s). From Figure 4-6, $K = 140 \times 10^{-6}$ at 1000°C. Therefore:

$$N_{RE} = \frac{VD}{K} = \frac{10\ m/s \times 2\ m}{140 \times 10^{-6}\ m^2/s}$$

$$N_{RE} = 143\ 000$$

A Reynolds Number of 143,000, in combination with good mixing, should be ample to provide high combustion efficiency and burnout.

For a rectangular or other shape of flue, the equivalent diameter (D_e) should be used. For example, for a rectangle, D_e is equal to four times the cross-sectional area divided by the wetted perimeter, i.e.

$$D_e = \frac{2*ab}{a+b}$$

where a and b are the dimensions of the sides of the rectangle.

In this example, $a = 2$ m and $b = 3$ m.

$$\text{Therefore, } D_e = \frac{2 \times 2 \times 3}{2 + 3} = 2.4 \text{ m}$$

This value of D_e would be used in lieu of D when applied to a non-circular cross section.

4.1.4.5 Fan Sizing

The fan power requirement is a function of air or gas flow rate (cubic metres per second), the pressure developed across the fan (kilopascals), and the fan efficiency. The efficiency of fans located downstream of air pollution control systems (clean gas) are normally in the range of 80 to 85%; fans located upstream of control devices (dirty gas) require specific designs which may be limited to the range of 60 to 75% efficiency. Efficiency will also drop as the fan becomes dirty, or when fan material erodes with wear. The fan power consumption is calculated as follows:

$$S = \frac{QWp}{h}$$

Q = flow rate, m^3/s

Wp = pressure across fan, kPa

h = fan efficiency

S = fan power consumption, kW

The flow rate of air or gas is determined from the incinerator calculations procedure described above. Typical pressure drops for fans associated with incinerator systems are listed in Table 4-9. These pressure values are values developed across the fan and should be used as Wp in the above equation.

Table 4-9
Typical Fan Pressure Drop Values

Fan Type	Pressure Drop
Forced Draft	1.0 - 1.5 kPa
Heated Gas Recirculation	1.0 - 2.0 kPa
Induced Draft	5.0 - 15.0 kPa
Supplemental Fuel Combustion Air	0.2 - 0.5 kPa
Fluidizing Air Blower	1.2 - 5.0 kPa

Note: The above values are typical of the pressure drop across a particular fan usage that should be used in determining fan power requirements.

4.1.4.6 ID Fan Sizing

An induced draft fan (ID fan) is the fan at the discharge of an incinerator that draws flue gas from the incinerator and discharges the gas through a stack to atmosphere. Many incinerators such as multiple hearth furnaces, grate type systems, and rotary kilns use ID fans.

Hot exhaust gases leaving incinerators may be first cooled by passage through a heat recovery section and/or passage through a water quench. Normally, sufficient water will be added to the hot gas stream to saturate that gas stream before entering the ID fan. When a fabric filter or an electrostatic precipitator is included within the system, only a limited amount of water is added; the gas flow would not be saturated and less water would be required.

Figure 4-7 relates the gas flow rate of saturated gas to dry air flow as a function of temperature. Determination of this ratio is necessary to allow a determination of the fan size. As noted previously, the assumption that flue gas has a dry component with the properties of dry air is used in these calculations.

As an example, if an ID fan is placed downstream of a wet scrubber which passes 18 000 kg/h (39,683 lb/h) of dry gas at a temperature of 50°C (122°F) entering the ID fan, the flow rate is calculated as follows:

> From Figure 4-7, at 50°C (122°F), one kg of dry air will have a volume of 1.03 m^3 (36 ft^3) when saturated with water. The 18 000 kg/h dry gas will, therefore, produce 18 000 kg/h x 1.03 m^3/kg, or 18 540 m^3/h of flue gas entering the ID fan. The ID fan can be sized on the basis of this flow.

4.1.4.7 Electric Power Requirements

As a general rule, when an ID fan is used in an incineration system, the total electric power requirements of that system can be approximated as double the ID fan rated kW. If an ID fan is not used, the power rating of each of the major items of equipment must be determined and totaled to obtain the facility power requirement.

4.1.5 Refractory Selection

4.1.5.1 Refractory Parameters

There are a wide variety of refractory and insulation products available. Their significant properties include:

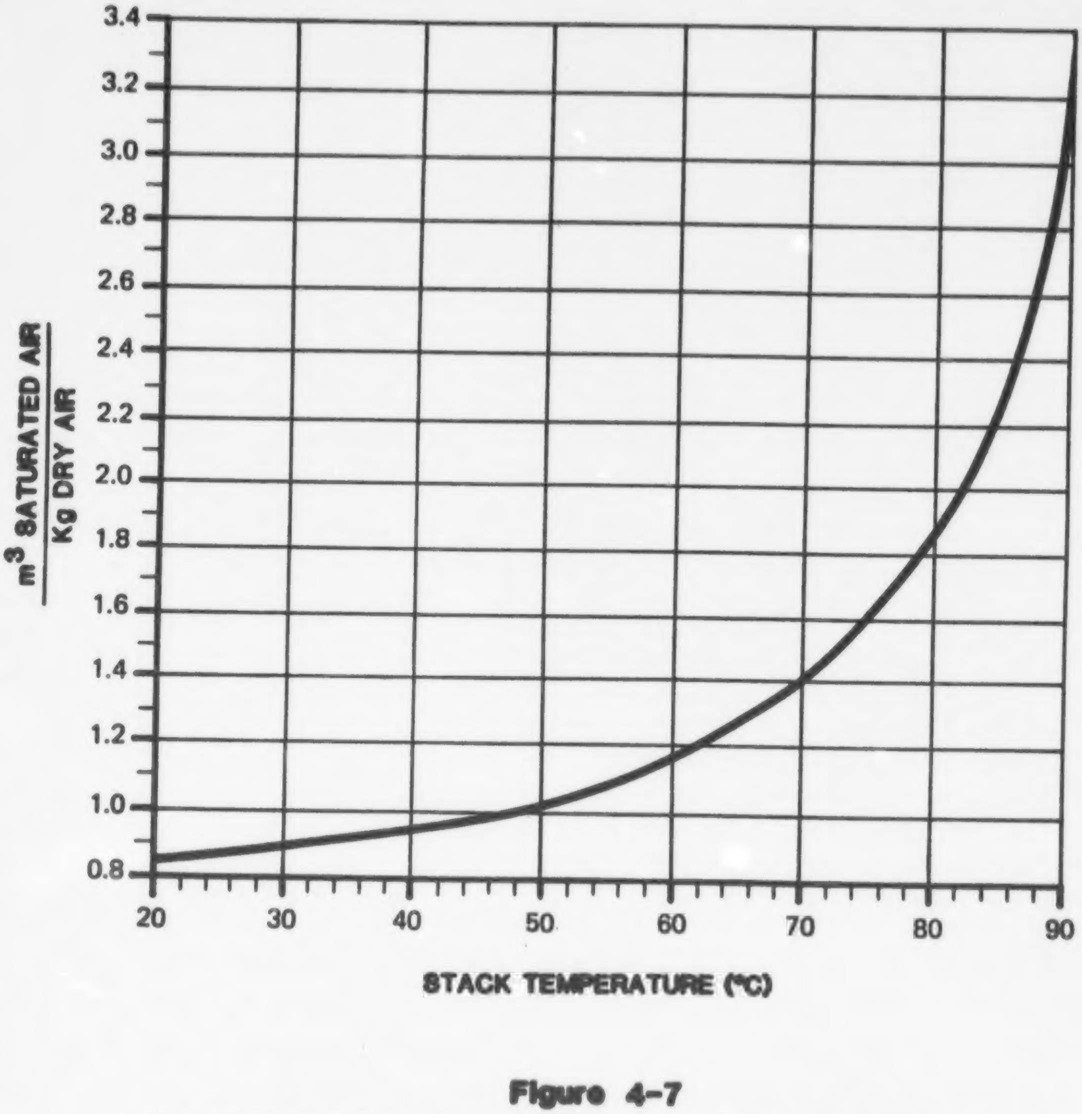


Figure 4-7

AIR HANDLING REQUIREMENTS FOR INDUCED DRAFT FANS
CUBIC METRES SATURATED AIR PER KILOGRAM DRY AIR
AS A FUNCTION OF STACK TEMPERATURE

- Abrasion - the washing away or physical destruction of material under forces due to physical contact with the gaseous, liquid, or solid materials on the hot face.

- Resistance to slagging or corrosion - the chemical process that destroys the refractory bond or the chemical integrity of the insulation.

- Mechanical shock or cold crushing strength - the ability to withstand handling and shipping without damage and impact strength at low temperature operations.

- Modulus of rupture - a standard measure of structural strength provided by load testing (ASTM Methods C16 and C216), providing another measure of mechanical shock resistance.

- Spalling - a deterioration of the surface of the refractory by flaking caused by abrasion, corrosion, mechanical or thermal shock.

- Porosity - the susceptibility to penetration by slags or gases, indicative of fly ash adherence.

- Maintaining strength under high temperature conditions.

- Insulating value - the ability to provide resistance to the flow of heat.

- Reheat (ASTM Method C113) - a measure of irreversible changes in linear dimensions under repeated heating and cooling.

- Specific heat - the amount of heat required to raise the temperature of a refractory material.

- Thermal expansion - the reversible change in linear dimensions under heating and cooling. Where refractory is used as a liner in a flue, for instance, the expansion of the refractory must be evaluated with respect to thermal expansion of the flue; if the expansions do not match, provision for material expansion must be considered.

- Resistance to the operating environment. Of particular interest is the performance of refractory in an oxidizing or reducing atmosphere; a reducing atmosphere, one deficient in oxygen, will tend to degrade refractory material containing iron or silicon components.

4.1.5.2 Castables (Refractory Concrete)

These materials are supplied dry and are to be mixed with water before installation. They are installed by either pouring (casting in place), troweling, pneumatic gunning (as with gunned fireproofing), or ramming. A castable refractory should provide a smooth, continuous, monolithic mass. Castable materials are normally placed in an area with pins, mesh, or other anchor devices to hold the refractory in place during placement and curing. Mesh, grid, studs, or needles may also be used to enhance the strength of the refractory installation.

Castable refractories are classified as dense or lightweight (insulating). Dense castables have excellent mechanical strength and low permeability. Their insulating properties, however, are relatively poor. As dense materials, over 1600 kg/m^3 (100 lb/ft^3) specific weight, they offer good resistance in wet service such as quencher linings.

Lightweight castables are excellent insulators. Castable materials have the advantage of relatively easy installation in irregular areas such as furnace transitions, burner openings, etc. Lightweight castable service temperatures are limited generally to below 1650°C (3000°F) whereas other castable refractories can sustain higher temperatures.

4.1.5.3 Firebrick

Conventional firebrick is kiln baked to uniform, controlled consistency and quality. The term firebrick refers to dense brick, over 1600 kg/m^3 (100 lb/ft^3) containing up to 44% alumina, normally placed in direct contact with the hot gas stream. Conventional firebrick has relatively poor insulating qualities.

Insulating firebrick (IFB) is a lightweight, porous brick, normally less than 800 kg/m^3 (50 lb/ft^3), which can be placed in direct contact with the gas stream and which provides good insulating characteristics. IFB is machined to its final shape providing excellent dimensional control as compared to conventional firebrick which is used as-cast.

IFB is lower in structural strength than firebrick and, because of its porosity, is a soft material not suitable for erosive gas streams, i.e., gas streams with high particulate components. This low abrasion resistance limits the maximum velocities allowed adjacent to it.

Where refractory brick is required and high abrasive resistance is necessary, firebrick will often be provided with insulation block as backup between the firebrick and the furnace/flue wall.

Silicon carbide refractory has relatively good thermal conductivity, good mechanical resistance, and abrasion resistance.

There are numerous types and grades of firebrick such as super-duty (high alumina content, improved strength and stability properties at high temperature), high-duty (good thermal shock resistance), low-duty (applicable for lower temperature and low abrasion service), and silicon carbide (excellent resistance to chemical attack), etc.

4.1.5.4 Incinerator Refractory Selection

Table 4-10 describes typical refractory applications for various incinerator sections.

4.1.6 Exhaust Gas Monitoring

Permanently mounted instrumentation is required for the measurement of temperatures, total hydrocarbons (or carbon monoxide), and opacity. Additionally, oxygen, carbon dioxide, and nitrogen oxides monitoring may be required.

As a minimum, temperature should be monitored and recorded for the gas leaving the furnace and the exhaust gas exiting the stack. Gaseous monitors should be located as close as practicable to the furnace exhaust point.

Special care must be exercised in locating opacity meters on systems which incorporate wet gas cleaning devices (such as a venturi scrubber). Entrained and/or condensing moisture downstream will appear and will affect the

Table 4-10
Refractory Selection for Incinerators

Incinerator Part	Temperature (°C) Range	Abrasion	Slagging	Mechanical Shock	Spalling	Fly Ash Adherence	Recommended Refractory
Charging gate	20-1400	Severe, very important	Slight	Severe	Severe	None	Super-duty
Furnace walls, grate to 2 m above	20-1400	Severe	Severe, very important	Severe	Severe	None	Silicon carbide or superduty
Furnace walls, upper portion	20-1400	Slight	Severe	Moderate	Severe	None	Super-duty
Stoking doors	20-1400	Severe, very important	Severe	Severe	Severe	None	Super-duty
Furnace ceiling	20-1400	Slight	Moderate	Slight	Severe	Moderate	Super-duty
Flue from combustion chamber	650-1400	Slight	Severe, very important	None	Moderate	Moderate	Silicon carbide or superduty
Combustion chamber	650-1400	Slight	Moderate	None	Moderate	Moderate	Super-duty
Combustion chamber ceiling	650-1400	Slight	Moderate	None	Moderate	Moderate	Super-duty
Breeching walls	650-1650	Slight	Slight	None	Moderate	Moderate	Super-duty
Breeching ceiling	650-1650	Slight	Slight	None	Moderate	Moderate	Super-duty
Subsidence chamber walls	650-1650	Slight	Slight	None	Slight	Moderate	Firebrick or Super-duty
Subsidence chamber ceiling	650-1650	Slight	Slight	None	Slight	Moderate	Firebrick or Super-duty
Stack	260-540	Slight	None	None	Slight	Slight	Firebrick or Super-duty

opacity reading. An upstream location will provide on indication of particulate and other carryover from the incinerator.

4.1.7 Acid Gas Corrosion

The exhaust gases from incinerators usually contain HCl, SO_2 and other acidic gases. Special design considerations may be necessary where:

- gas temperatures will be below 150°C (300 °F; potential for acid gas condensation) and/or
- heat recovery media (e.g. boiler tubes) will be above 370°C (700°F; potential for acid gas corrosion)

4.2 INCINERATOR SYSTEMS

4.2.1 Mass Burn Incinerators

The term "mass burn incineration" describes the process by which bulk, heterogeneous solid waste is fed and burned as-received without pretreatment or pre-sorting. Several types of incineration equipment can be used to accomplish this task, from the simplest single-chamber units through to multi-chamber incinerators and large central waste incineration systems. The principal types of mass-burning incineration equipment are described below.

4.2.1.1 Single-Chamber Incinerators

Equipment Description. A typical single-chamber incinerator is shown in Figure 4-8. Solid waste is placed on the grate and ignited. Combustion air is induced to flow into the combustion chamber through the underfire and overfire ports and up the stack into the atmosphere. Underfire air provides oxygen to burn the waste, while the overfire air supply promotes combustion of the flue gas. Ash falls

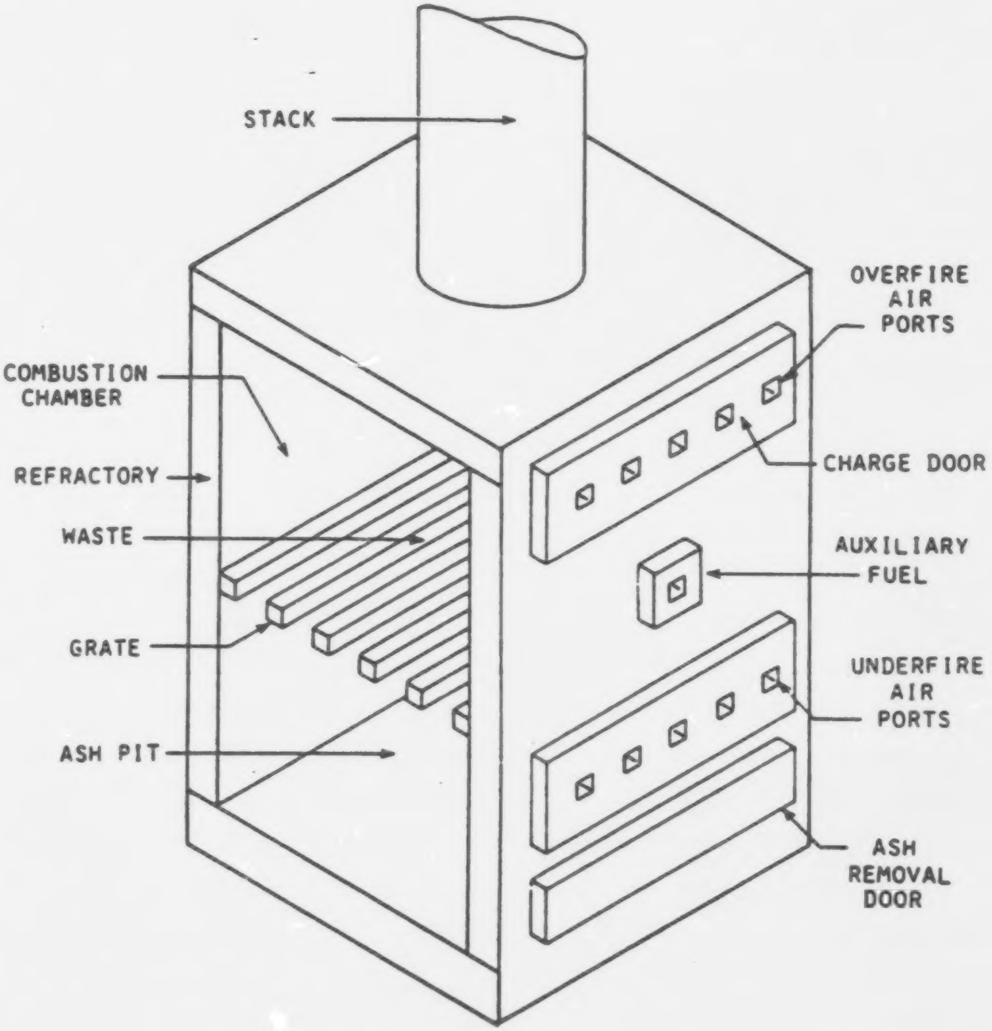

STACK
OVERFIRE AIR PORTS
COMBUSTION CHAMBER
REFRACTORY
CHARGE DOOR
WASTE
AUXILIARY FUEL
GRATE
UNDERFIRE AIR PORTS
ASH PIT
ASH REMOVAL DOOR

Figure 4-8
SINGLE CHAMBER INCINERATOR

through the grate to an ash pit and is manually removed at the conclusion of a burn.

The single-chamber incinerator is typically operated on a batch-charged basis; it is provided with an auxiliary fuel burner; and it may have an afterburner within the stack to reduce the emissions of unburned carbonaceous particles and hydrocarbon gases.

Application. Single-chamber incinerators have been used for combustion of virtually all types of solid waste. If the waste material does not have sufficient heat value to support its own combustion, the unit must be equipped with an auxiliary fuel burner.

Development Status. Various designs of the single-chamber incinerator have been used in applications such as the flue-fed apartment building incinerator for burning domestic waste, or the teepee burner for destruction of refuse, wood, and agricultural waste. The largely uncontrolled nature of the combustion process in these units has led to a decrease in their popularity with the advent of more stringent air pollution control standards. In particular, flue-fed incinerators are frequently prohibited due to the potential for overloading and piling of the waste. Air distribution is generally poor in this equipment, resulting in poor combustion and the generation of smoke and odour.

Operating Practice. Due to the significant variation in design of single chamber incinerators and the lack of control over combustion air feed rates, it is difficult to cite generic operating practice for this incinerator type. However, in general most systems operate at between 100% and 300% excess air. Systems equipped with afterburners normally maintain a temperature of 750°C to 1000°C (1380°F to 1830°F) for 0.5 to 1.0 seconds to reduce stack emissions.

Guideline. Single chamber incinerators should be replaced by a modern package unit which meets current guidelines, or alternate arrangements made to dispose of the wastes. Consideration might be given to upgrading units to meet the aspects of Policy 01-01 and 01-03 but it is highly unlikely that such conversion would be practical or economical.

Single chamber incinerators should not be used for industrial wastes, pathological wastes, or wastes containing hazardous or toxic constituents.

4.2.1.2 Multiple-Chamber Incinerators

Equipment Description. To overcome the problem of incomplete combustion associated with single-chamber incinerators, multiple-chamber units were developed. A primary chamber is used for combustion of the solid waste while the secondary chamber provides the residence time, temperature, and supplementary fuel for combustion of the unburned products carried over from the primary chamber.

There are two basic types of multiple-chamber incinerators, retort and in-line systems:

- Retort Incinerator: This unit is a compact incinerator in the form of a cube with multiple internal baffles. The baffles are positioned to guide the combustion gases through 90° turns in both lateral (horizontal) and vertical directions. At each turn, ash (soot) drops out of the flue gas flow. The primary chamber has elevated grates for burning of the waste and an ash pit for collection of ash residue. A cutaway view of a typical retort incinerator is shown in Figure 4-9.

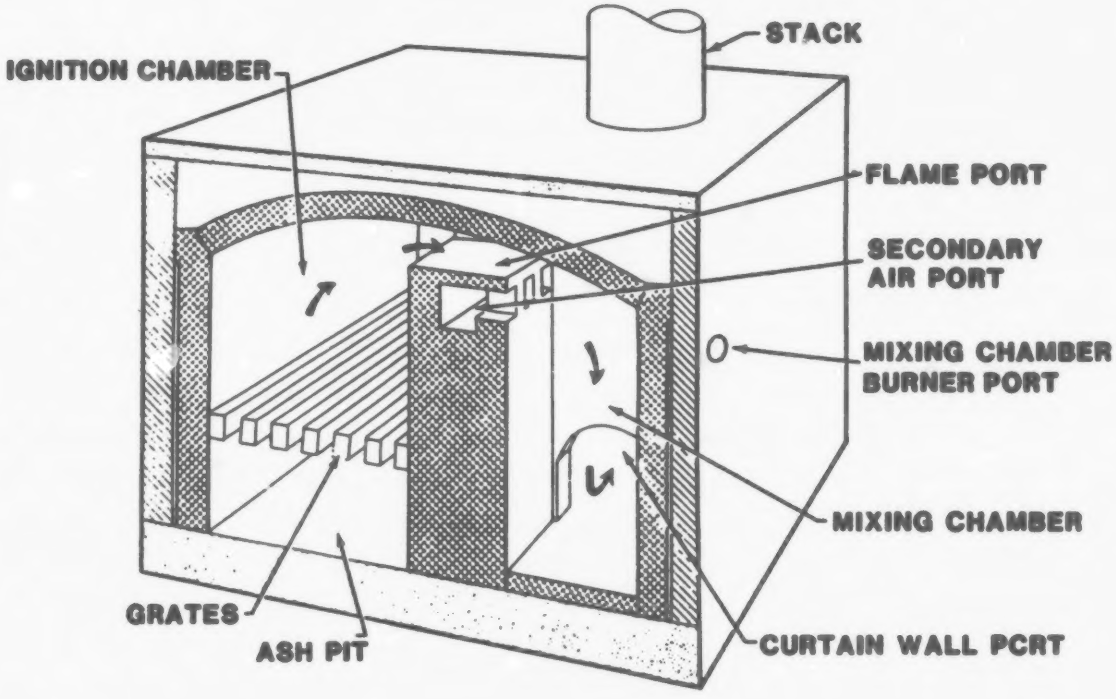

STACK
IGNITION CHAMBER
FLAME PORT
SECONDARY AIR PORT
MIXING CHAMBER BURNER PORT
MIXING CHAMBER
CURTAIN WALL PCRT
GRATES
ASH PIT

Figure 4-9

RETORT INCINERATOR

- In-Line Incinerator: This is a larger unit than the retort incinerator. Flow of combustion gases is straight through the incinerator axially, with abrupt changes in direction as shown in Figure 4-10. Waste is charged on the grate, which can be either stationary or moving. As with the retort type, changes in the flow path and flow restrictions in an in-line incinerator provide settling out of larger airborne particles and increased turbulence for more efficient burning.

With both types of systems, supplemental fuel burners are provided in both the primary and secondary chambers. Depending upon the nature of the waste burned, the fuel supply in the primary chamber may be unnecessary after startup although the secondary chamber normally requires a continuous fuel supply (at least a pilot flame). Overfire and underfire air to the primary chamber is normally aspirated through ports in the wall of the furnace, or is supplied at a controlled rate by forced draft fans. Additional air is added to the secondary chamber to ensure complete combustion.

Application. Multiple-chamber incinerators are commonly used for all types of solid waste as well as for specialty applications such as incineration of pathological wastes, crematory incinerators, and metal drum reclamation.

Development Status. Multiple-chamber incinerators are commercially available, many as packaged systems. Retort incinerators are normally used for batch or semi-continuous operation in the capacity range of 10 to 350 kg/h (22 to 772 lb/hr). In-line incinerators are normally provided in the 225 to 900 kg/h (496 to 1,984 lb/hr) range and may be equipped with automatic charging and/or ash removal equipment on units above 20 kg/h (44 lb/hr) capacity.

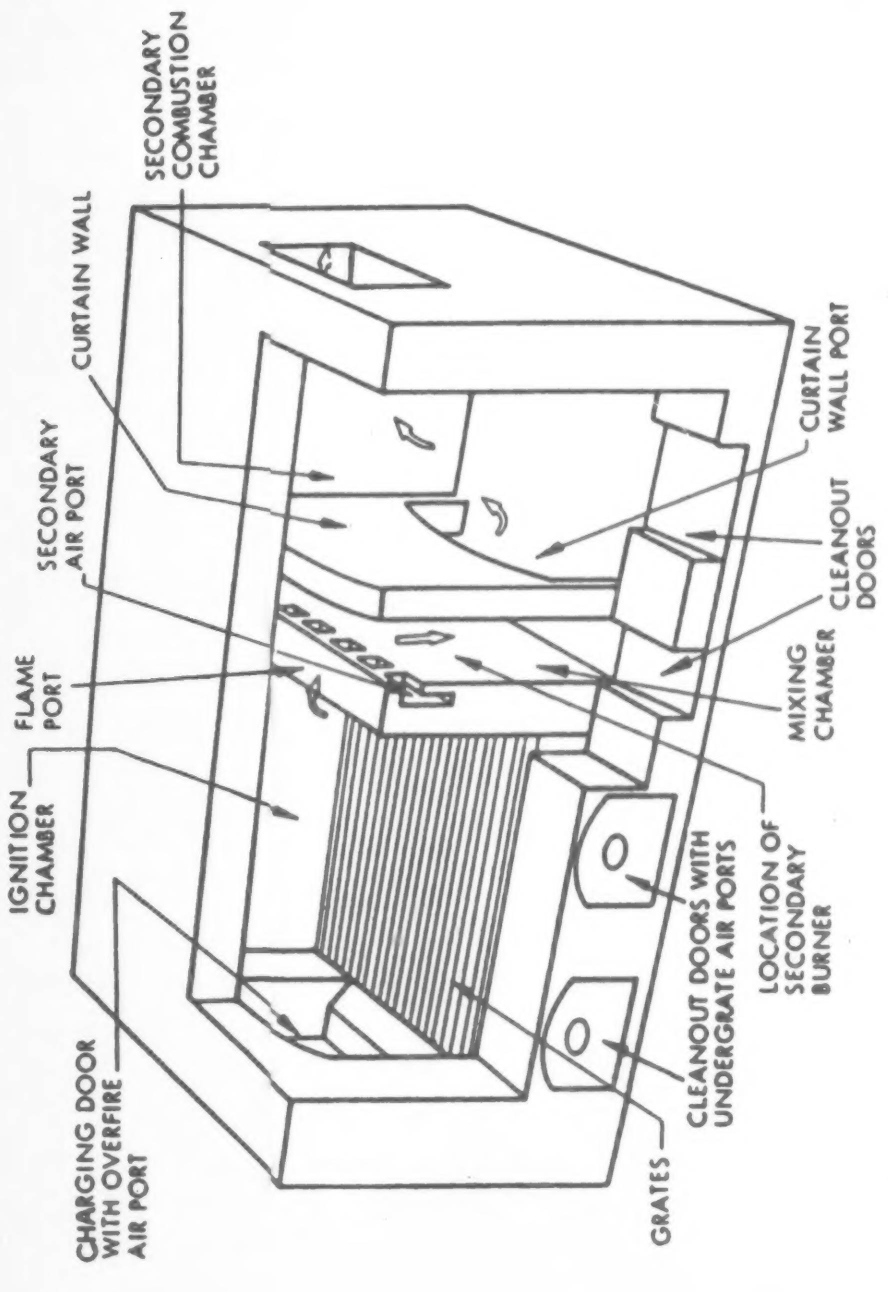

CHARGING DOOR WITH OVERFIRE AIR PORT
IGNITION CHAMBER
FLAME PORT
SECONDARY AIR PORT
CURTAIN WALL
SECONDARY COMBUSTION CHAMBER
GRATES
CLEANOUT DOORS WITH UNDERGRATE AIR PORTS
LOCATION OF SECONDARY BURNER
MIXING CHAMBER
CLEANOUT DOORS
CURTAIN WALL PORT

Figure 4-10
IN-LINE INCINERATOR

Operating Practice. Dimensional data for typical retort and in-line incinerators of varying capacity are provided in Figures 4-11 and 4-12, respectively. Although they represent the product of a single manufacturer, the dimensional data can be considered generic. They are typically operated at a temperature of 760°C to 1000°C (1400°F to 1832°F) in the secondary chamber and normally use approximately 200% excess air. Approximately half of the required air enters as leakage. Of the balance, 70% should be provided in the primary combustion chamber as overfire air, 10% as underfire air, and 20% in the mixing or secondary chamber.

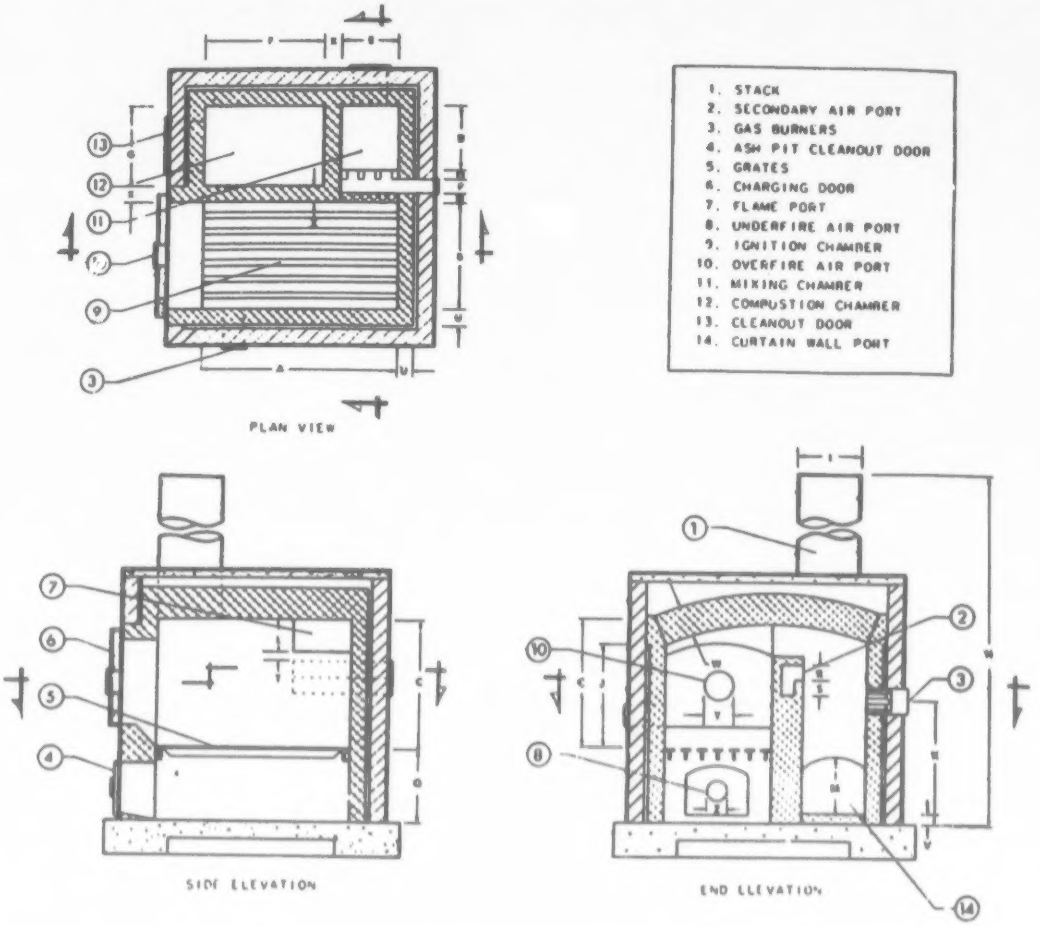
They are applicable for refuse, trash, rubbish and biomedical waste, but it is generally difficult to incorporate the air emission control equipment required to meet Policy 01-10.

Guideline. Multiple-chamber incinerators should meet all the aspects of Policy 01-01 and 01-03 and the additional aspects as discussed in Section 4.1.2.

As well when burning biomedical waste, a grate should not be used. A solid hearth to support the waste is acceptable. The operating temperature should be no less than 760°C (1400°F) in the primary chamber and 1000°C (1830°F) minimum in the secondary combustion chamber.

4.2.1.3 Pyrolysis Systems

Process Description. Pyrolysis is the destruction of carbonaceous material in the presence of heat and substoichiometric oxygen level. In practice the heat is provided by combustion of a portion of the waste. Under ideal conditions, the pyrolysis of pure cellulose will produce



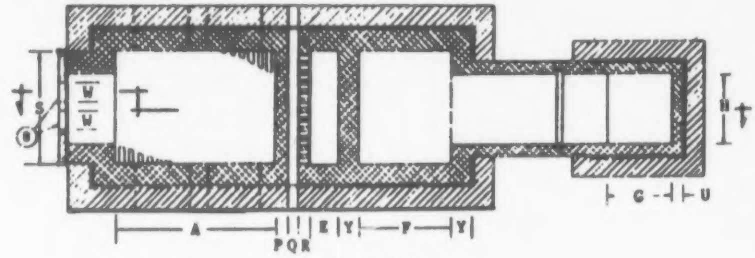
1. STACK
2. SECONDARY AIR PORT
3. GAS BURNERS
4. ASH PIT CLEANOUT DOOR
5. GRATES
6. CHARGING DOOR
7. FLAME PORT
8. UNDERFIRE AIR PORT
9. IGNITION CHAMBER
10. OVERFIRE AIR PORT
11. MIXING CHAMBER
12. COMBUSTION CHAMBER
13. CLEANOUT DOOR
14. CURTAIN WALL PORT

DESIGN STANDARDS, MULTIPLE CHAMBER RETORT INCINERATORS, DIMENSIONS IN CENTIMETERS

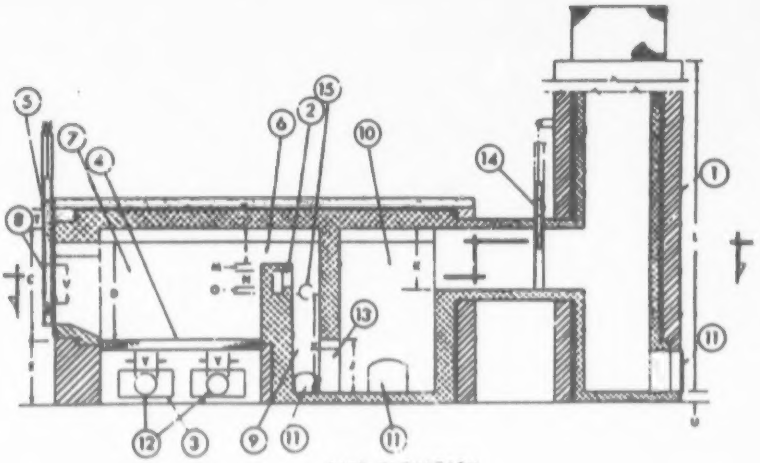
INCINERATOR SIZE (KG/HR)	A	B	C	D	E	F	G	H	I	J	K	L	M
25	80	34	57	23	17	51	34	548	20	47	51	10	25
45	103	46	72	34	23	69	46	579	30	58	71	13	38
70	114	57	85	39	29	74	57	609	36	69	90	13	42
110	137	69	95	46	34	91	69	670	46	76	101	19	46
225	194	91	120	69	46	126	91	853	61	93	123	32	58
340	217	125	137	91	57	137	114	975	76	101	130	38	71
450	240	137	151	91	69	149	114	1060	86	114	138	44	76

INCINERATOR SIZE (KG/HR)	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
25	11	6	6	23	6	6	6.35	114	6	11	11	15	10
45	6	6	10	37	13	0	6.35	114	6	11	11	20	13
70	11	6	11	46	13	6	6.35	114	6	11	11	23	15
110	11	11	11	51	13	6	6.35	114	6	11	11	30	15
225	23	11	11	66	13	13	6.35	228	11	23	23	41	20
340	23	11	11	64	13	25	6.35	228	11	23	23	46	20
450	23	11	11	70	19	32	6.35	228	11	23	23	56	25

Figure 4-11
DIMENSIONAL DATA FOR RETORT INCINERATORS



PLAN VIEW



SIDE ELEVATION

1. STACK
2. SECONDARY AIR PORTS
3. ASH PIT CLEANOUT DOORS
4. GRATES
5. CHARGING DOOR
6. FLAME PORT
7. IGNITION CHAMBER
8. OVERFIRE AIR PORTS
9. MIXING CHAMBER
10. COMBUSTION CHAMBER
11. CLEANOUT DOORS
12. UNDERFIRE AIR PORTS
13. CURTAIN WALL PORT
14. DAMPER
15. GAS BURNERS

DESIGN STANDARDS: MULTIPLE-CHAMBER, INLINE INCINERATORS, DIMENSIONS IN CENTIMETERS

INCINERATOR SIZE (KG/HR)	A	B	C	D	E	F	G	H*	I	J	K	L	M
407.7	217	126	131	114	40	137	69	69	24	61	46	10	11
543.6	240	137	137	121	46	15	80	80	28	74	57	11	11
815.4	251	194	165	140	46	183	91	91	32	81	69	12	11
1087.2	274	229	177	146	57	202	103	103	38	91	80	12	11

INCINERATOR SIZE (KG/HR)	N	O	P	Q	R	S	T	U	V	W	X	Y
407.7	13	19	23	6	6	76	23	11	13	28	130	18
543.6	13	25	23	6	6	76	23	11	18	30	132	20
815.4	13	19	23	11	11	76	23	11	20	36	156	23
1087.2	13	25	23	11	11	76	23	11	23	38	161	25

* DIMENSIONS IN THIS COLUMN ARE IN METERS

Figure 4-12
DIMENSIONAL DATA FOR IN-LINE INCINERATORS

combustible off-gases (methane and carbon monoxide), water (steam), and a residual char (carbon). The ideal pyrolysis reaction, of which there are many variations, is as follows:

$$C_6H_{10}O_5 \rightarrow CH_4 + 2CO + 3H_2O + 3C$$

In the actual destruction of waste, the off-gases are a mixture of many simple and complex volatile organic compounds, and the char is often a liquid containing residual carbon or tars and ash. In general, volatile gas production increases with increasing temperature, whereas the generation of tars and other liquors is greatest at lower temperatures.

Application. The only commercial pyrolysis system that has been found to operate successfully in North America is one that handles industrial semi-liquid and sludge wastes at a number of pharmaceutical plants in the United States. The use of pyrolysis for the destruction of municipal sludge and solid wastes has not been successfully demonstrated to date on a commercial scale.

Development Status. Pyrolysis has been used as an industrial process for many years for the production of charcoal from wood chips, coke and coke gas from coal, fuel gas and pitch from heavy hydrocarbon still bottoms, etc. The process has seen promotion for waste destruction only since the late 1960s. Commercial pyrolysis systems for municipal waste destruction, such as Union Carbide's PUROX process, the ANDCO-TORRAX process, and Monsanto's Landguard system, are no longer actively marketed in North America.

Operating Practice. Pyrolysis reactors typically operate at temperatures of between 500°C and 900°C (930°F and

1650°F) with waste residence times of 12 to 15 minutes. Systems designed to generate heat internally by combustion use less than the stoichiometric oxygen requirement. Depending on the waste characteristics and process design features, off-gas will typically have a heating value of between 5000 and 15 000 kJ/m^3 (134 to 403 Btu/ft^3) which represents about 80% of the heat energy originally contained within the waste. The solid residue normally represents less than 5% of the original waste volume although pyrolysis systems will have a higher fixed carbon content than excess air incinerators. Pyrolysis units have been found to be applicable to the destruction of organic industrial sludges.

A number of problems have been found in the application of pyrolysis systems to the destruction of solid waste. The temperatures developed in the reactor are sufficiently high to keep the ash and other residue components molten. It has been difficult in many of these systems to control the solidification of the molten material as it leaves the reactor. Excessive slagging has occurred at the residue outlet and this slag, which is a result of uneven cooling of the molten ash, clogs the reactor, preventing ash discharge. The reactor must be shut down until the slag formation has been removed.

Another problem that has been found with pyrolysis systems is the generation of small particulate matter and organics in the off-gas. The nature of the pyrolysis reaction is that it does not burn the waste; it thermally decomposes the waste, generating a fairly dirty exhaust stream rich in organics and containing significant amounts of small carbonaceous solid particles. An afterburner must be employed to burn out organics in the off-gas.

Most pyrolysis systems include an emergency exhaust stack that is used to bypass critical equipment when operating problems occur such as a loss of cooling water in downstream equipment or the failure of the induced draft fan. An emergency exhaust stack must never be placed upstream of the afterburner. This stack discharges to atmosphere and the hot gases, which are rich in organics, will burn upon contact with a source of air (or oxygen). Placing an exhaust stack between the pyrolysis reactor and the afterburner will result in, at best, uncontrolled burning out the stack, and at worst, the discharge of organics which may pose a threat to human health. There is also a high probability that such a discharge will result in an explosion as the hot organic-laden gases react with the surrounding air.

A Japanese firm has developed a sludge incineration system (multiple hearth furnace) that is designed specifically for operation in the pyrolysis mode. It has a minimal amount of openings in its shell, and an afterburner is included as an integral part of the furnace structure. An American firm has also developed a sludge pyrolysis system which is in use treating sludge from pharmaceutical operations. This furnace is a single rotary hearth unit, with an afterburner slightly removed from the furnace itself. Careful attention is paid to minimizing air leakage into the system. Without dedicated designs such as these, the use of pyrolysis for waste disposal can result in severe problems. Modification of an existing multiple hearth furnace, for instance, from excess-air operation to pyrolysis operation is difficult and dangerous. The furnace contains numerous openings which are potential sources of uncontrolled air infiltration. For instance, the accidental opening of an access door or opening a damper too far or too quickly which admits air to the furnace can result in a conflagration.

Guideline. Pyrolysis reactors should meet all the aspects of Policy 01-01 and 01-03, and the additional aspects discussed in Section 4.1.2. The specific treatment of the pyrolysis gas (e.g. removing condensibles) should be considered in developing the combustion and air pollution requirements for the fuel gas produced.

4.2.1.4 Starved Air Incinerators

Equipment Description. Starved Air or Controlled Air incinerators, also referred to as Modular Combustion Units (MCUs), are two-chamber incinerators in which less than the stoichiometric air requirement is provided in the primary chamber. The thermal reactions occurring in this chamber are a combination of combustion and pyrolysis. The products of the pyrolysis reaction (typically methane and carbon monoxide off-gases and unburned carbon) flow to a secondary chamber where excess air is added, also at a controlled rate, to effect complete combustion. The combustion process is so well controlled with these units that very low particulate emissions may be achieved.

Figure 4-13 illustrates some typical configurations of controlled air incinerators.

Application. MCUs were originally developed for the destruction of paper waste. They are also applicable to the destruction of other solid wastes and their secondary chamber can be used for the destruction of gaseous or liquid waste in suspension. Work has been done on the incineration of sewage sludge with municipal refuse in an MCU with limited success.

The nature of the MCU process is such that agitation of the waste feed is minimal. Materials requiring agitation for effective combustion, such as powdered carbon or pulp

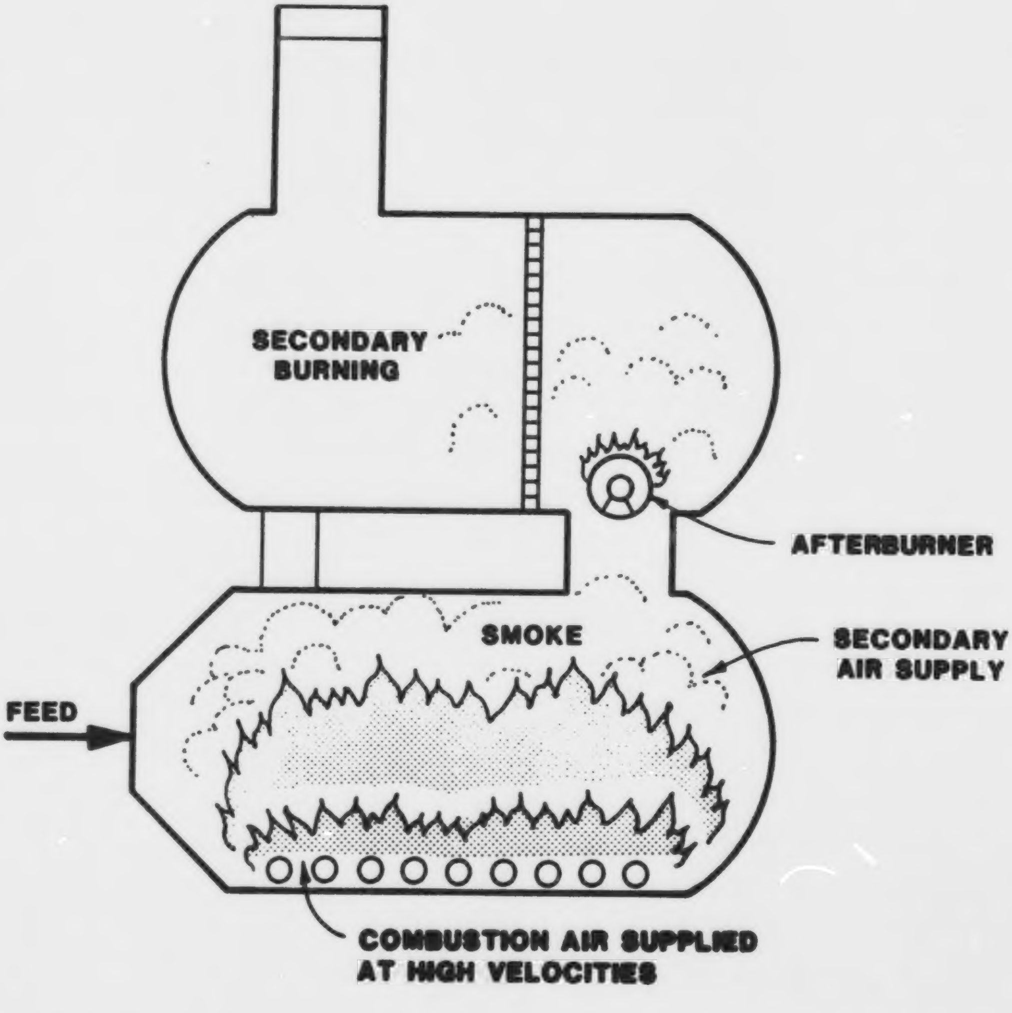

SECONDARY BURNING
AFTERBURNER
SMOKE
SECONDARY AIR SUPPLY
FEED
COMBUSTION AIR SUPPLIED AT HIGH VELOCITIES

Figure 4-13
MODULAR CONTROLLED-AIR INCINERATOR CONFIGURATION

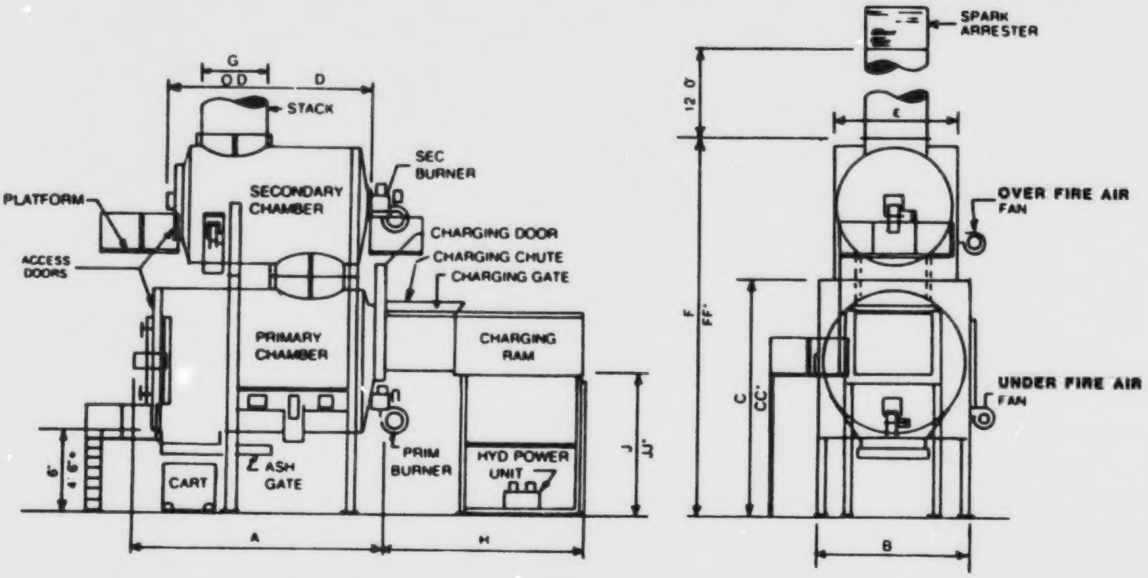
wastes, are not appropriate candidates for incineration in an MCU.

Development Status. MCUs are manufactured by several vendors as "standard" models that are modified to suit a customer's specific needs (e.g. waste type, heat recovery requirements, etc.). Smaller units, under 340 kg/h (750 lb/hr), are normally batch fed using a hopper/ram assembly or double ram charging system to minimize the infiltration of air into the primary chamber during charging.

Larger units are usually provided with a continuous waste charging system, a screw feeder, or a series of moving grates. Ash removal from smaller units is usually a manual operation, whereas larger systems may be equipped with automatic ash removal and quenching equipment.

Operating Practice. Most of these units are provided with heat recovery. Normally, firetube boilers are used for the generation of steam or hot water. Dimensional data for a typical MCU system are shown in Figure 4-14. This equipment, although provided by a single manufacturer, can be considered generic. The temperature in the primary chamber is usually maintained in the range of 760°C to 870°C (1400°F to 1600°F), whereas the secondary chamber may operate at temperatures as high as 1100°C (2010°F). With paper-type wastes the secondary chamber temperature has typically been in the 870°C to 1000°C (1600°F to 1830°F) range.

Typically 70 to 80% of the stoichiometric air requirement is introduced into the primary chamber. Approximately 140 to 200% of the primary chamber's off-gas stoichiometric requirement is fed to the secondary chamber. The net air flow to the system is in the range of 100% to 200% of the stoichiometric requirement.


G
OD
D
STACK
SEC BURNER
PLATFORM
SECONDARY CHAMBER
CHARGING DOOR
CHARGING CHUTE
CHARGING GATE
ACCESS DOORS
PRIMARY CHAMBER
CHARGING RAM
6'
4'6"
CART
ASH GATE
PRIM BURNER
HYD POWER UNIT
J
JJ'
A
H
SPARK ARRESTER
12 0'
E
OVER FIRE AIR FAN
F
FF'
C
CC'
UNDER FIRE AIR FAN
B

DESIGN STANDARDS: TYPICAL MODULAR COMBUSTION UNTIS, DIMENTIONS IN METERS

CAPACITY (KG/HR)	A	B	C	CC	D	E	F	FF	G	H	J	JJ	CHUTE CAPACITY (m^3)
45- 75	2.6	1.4	1.5	2.7	1.9	1.1	2.7	4.0	0.4	3.4	0.6	1.8	0.4
100- 160	2.9	1.7	1.8	3.0	2.1	1.4	3.4	4.6	0.5	3.4	0.6	1.8	0.4
145- 240	2.9	1.8	2.0	3.2	2.1	1.7	3.8	5.0	0.5	3.4	0.8	2.0	0.8
200- 320	3.0	2.0	2.1	3.4	2.4	1.7	4.0	5.2	0.7	3.4	0.8	2.0	0.8
300- 475	3.5	2.3	2.4	3.7	2.4	1.8	4.6	5.8	0.8	4.0	0.8	2.0	1.5
400- 635	3.7	2.4	2.6	3.8	2.7	2.0	4.9	6.1	0.9	4.0	1.1	2.4	1.5
600- 950	3.8	2.9	3.0	4.3	2.9	2.6	5.9	7.2	1.0	4.0	1.1	2.6	2.3
885-1450	4.4	3.2	3.4	4.6	3.0	2.9	6.6	7.8	1.2	4.0	1.2	2.7	2.3
1050-1775	4.9	3.4	3.5	4.7	3.7	2.9	6.7	7.9	1.3	4.3	1.7	2.9	3.1
1300-2150	5.5	3.5	3.7	4.9	4.3	2.9	6.9	8.1	1.4	4.3	1.7	2.9	3.1

Figure 4-14
DIMENSIONAL DATA FOR TYPICAL MCU SYSTEM

Air feed rate to each chamber is controlled by temperature. Below the stoichiometric air requirement (in the primary chamber) temperatures increase with increasing airflow, whereas in the secondary chamber, where excess air is provided, increasing airflow decreases the operating temperature. Automatic fan damper positioning is normally used to control the airflow and, thus, temperature in each chamber.

MCUs are applicable to trash in all incinerator sizes. In larger sizes (over one tonne per hour), they are applicable to refuse burning. They have limited application in industrial waste disposal and have demonstrated mixed results in the disposal of biomedical wastes.

Starved air units require close control of air injection into the furnace, particularly into the primary chamber. Any uncontrolled source of air (such as through the charging door or around the ash discharge ram) will increase burning and will reduce the heating value of the gas stream entering the secondary chamber. Normally, the secondary chamber is provided with burners sized to burn out flue gas with a significant organic content. It will not have sufficient heat release to effectively burn out gas without significant organic content. The more air introduced into the primary chamber, the poorer the waste destruction in the primary chamber and the more difficult it is to destroy organics in the secondary chamber.

Air infiltration is difficult to control. The starved air furnace is operated under negative pressure to prevent leakage of hot, dirty flue gases from the furnace. An air lock system should be provided on the charging door, which typically opens from four to ten times per hour, staying open from 30 seconds to 1-1/2 minutes per charge. Likewise, the ash ram system should be provided with an air lock.

Starved air systems are sometimes specified on the basis of trash or pure paper waste. This is not a realistic means of selection. These wastes are rarely, if ever, found. If sized on these high quality wastes, the furnace will generally not have sufficient supplemental fuel heat output to effectively destroy wastes normally found, such as refuse or garbage (cafeteria wastes). This equipment should be specified for a capacity to incinerate an actual waste stream, not a theoretical superior waste.

Guideline. Controlled air incinerators should meet all requirements of Policy 01-01 and 01-03 and the additional aspects discussed in Section 4.1.2. As well when burning biomedical waste, a grate should not be used. A solid hearth to support the waste is acceptable.

The operating temperature should be in the range of 400°C to 760°C (750-1400°F) in the primary chamber.

An air lock system should be provided with controlled air units of 500 kg/h (1,102 lb/hr) capacity or less to reduce infiltration of air into the unit. This system must include dual charging rams as well as duplicate charging doors. Alternate designs may be considered if they can be demonstrated to be as effective as double rams.

4.2.1.5 Central Waste Incinerators

Equipment Description. Central waste incinerators are those which accept waste from several external sources for destruction in a central facility. They are usually large, (in excess of 50 t/d [55 T/d]) continuously operated installations equipped with heat recovery equipment. Waste is burned in these incinerators without pre-processing.

The features of large central mass burning incinerators are distinguished by the design of the grate system. The grate must transport refuse through the furnace and promote combustion by providing adequate agitation without contributing to excessive particulate emissions.

European systems are typically equipped with inclined grates that move the waste through the furnace by reciprocating or rotating drum action as illustrated in Figure 4-15. Stationary circular grates with rotating rabble arms, travelling grates, and rocking grates are also used.

As the waste moves progressively through the furnace, it is dried, burned, and combusted to ash. Approximately 40 to 60% of the total air entering the furnace is provided as underfire air to cool the grates and prevent ash slagging. The balance is supplied as overfire air to completely combust the flue gas and particulate rising from the grates.

Many central waste incineration systems are built with waterwall construction in addition to boiler tubes within the flue gas steam (convection sections) to maximize energy recovery from the incinerator. Refractory-lined combustion chambers with a separate downstream boiler section may also be used in lieu of waterwall construction. If refractory walls are used, higher excess air is required to control the operating temperature.

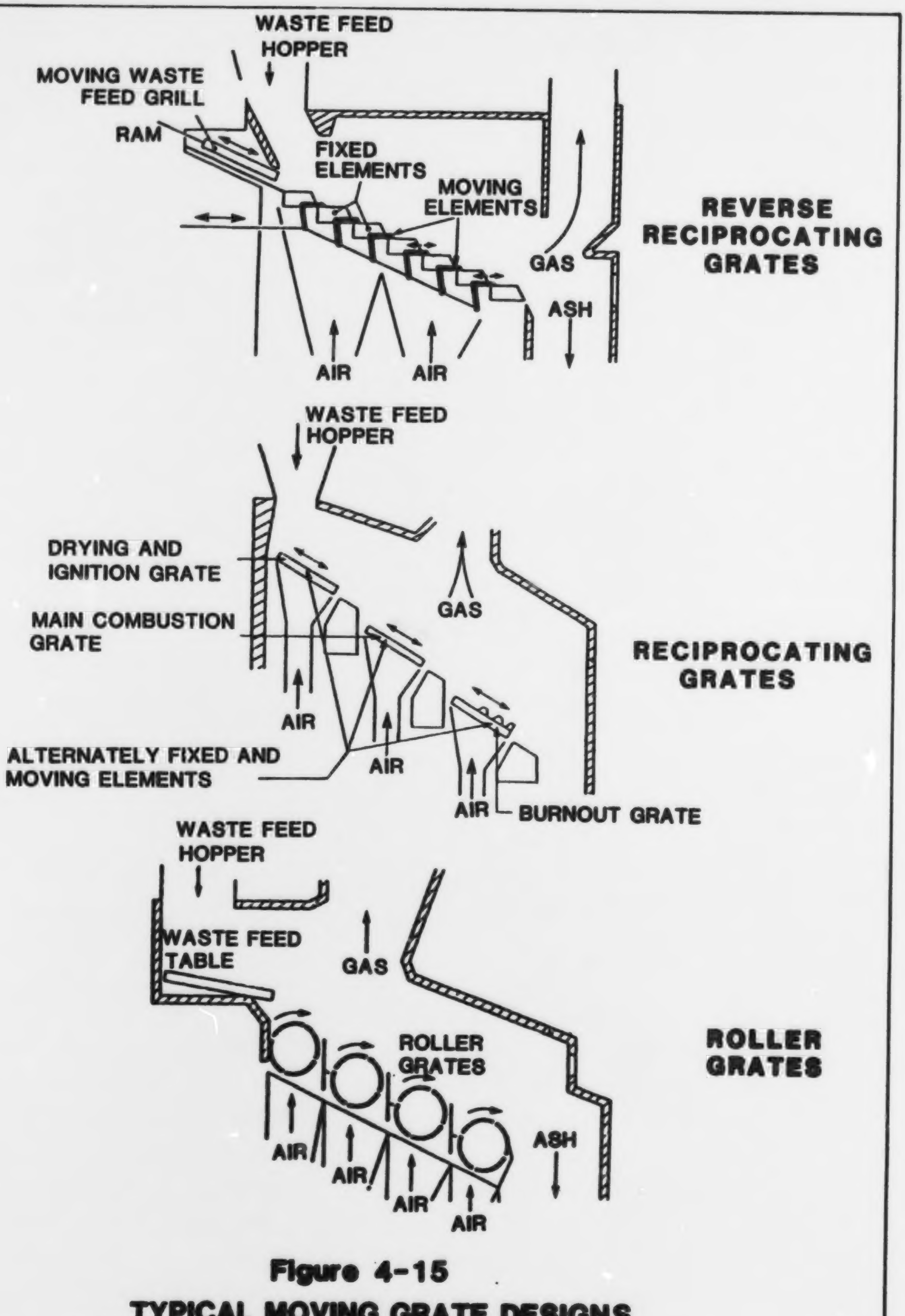

WASTE FEED HOPPER
MOVING WASTE FEED GRILL
RAM
FIXED ELEMENTS
MOVING ELEMENTS
GAS
ASH
AIR
AIR
REVERSE RECIPROCATING GRATES
WASTE FEED HOPPER
DRYING AND IGNITION GRATE
MAIN COMBUSTION GRATE
GAS
AIR
ALTERNATELY FIXED AND MOVING ELEMENTS
AIR
AIR
BURNOUT GRATE
RECIPROCATING GRATES
WASTE FEED HOPPER
WASTE FEED TABLE
GAS
ROLLER GRATES
ASH
AIR
AIR
AIR
AIR
ROLLER GRATES

Figure 4-15

TYPICAL MOVING GRATE DESIGNS FOR CENTRAL WASTE INCINERATORS

Application. Central waste incineration systems are used primarily for refuse incineration. The practice has been more prevalent and more long-standing in Europe than in North America. In Canada, mass burning of municipal refuse in central waste incinerators is being carried out at central incineration facilities at Quebec City, St. David, and Montreal, Quebec; Toronto and Hamilton, Ontario.

Development Status. Mass burning of refuse in central incineration facilities is a commercially demonstrated technology. Due to the relatively large size of such units and unique features of each system with respect to waste handling, energy recovery, etc., these facilities are normally designed and built to meet each customer's specific needs.

Operating Practice. Operating temperatures in mass-burning central waste incinerators are normally maintained in the order of 1000°C (1832°F) and refuse residence time on the grate ranges from 20 to 45 minutes. Refractory wall systems normally require 100 to 150% excess air to maintain operating temperatures, whereas waterwall systems require only about 80% excess air. This offers the advantages of a smaller furnace volume and reduced NO_x formation with the latter system, due to the lower airflow. Waterwalls extract heat from the burning waste. Without waterwalls, where the furnace chamber is lined with refractory, the furnace temperature must be controlled by the injection of cool air. In refractory or waterwall furnaces the maximum temperatures should be below 1100°C (2010°F), the temperature at which slagging problems will begin to occur. Table 4-11 lists temperatures at which ash from a typical refuse composition will begin to deform.

Table 4-11
Ash Fusion Temperatures

	Reducing Atmosphere °C (°F)		Oxidizing Atmosphere °C (°F)	
Refuse				
Initial Deformation	1030-1130	(1880-2060)	1110-1150	(2030-2100)
Softening	1200-1300	(2190-2370)	1240-1320	(2260-2410)
Fluid	1320-1400	(2400-2560)	1360-1480	(2480-2700)
Coal				
Initial Deformation	1060-1100	(1940-2010)	1100-1240	(2020-2270)
Softening	1080-1200	(1980-2200)	1160-1340	(2120-2450)
Fluid	1230-1430	(2250-2600)	1310-1430	(2390-2610)

SOURCE: C.R. Brunner, INCINERATION SYSTEMS: Selection and Design, Van Nostrand Reinhold, 1984.

Underfire air is provided beneath the grates to prevent overheating of the grate system and to supply part of the waste combustion air requirement. Air is also provided above the grates (overfire air) to burn off the products of combustion of the waste and to properly direct flue gas flow within the furnace. Underfire air will comprise from 40% to 60% of the air flow to the furnace, with the overfire air flow inserting the balance of the air required for incineration.

White goods (stoves, refrigerators, etc.) must be removed from the waste feed. With some systems there is limited ability to handle waste tires, and they must be removed or distributed throughout the daily feed.

The mass burn waterwall furnace is designed to generate steam (or hot water) as well as to incinerate waste. Its design must include provisions to minimize boiler tube corrosion.

There are two types of corrosion mechanisms normally associated with waste burning facilities. One is dew point and the other is high temperature corrosion. Dew point corrosion occurs when the flue gas stream is reduced in temperature to less than 150°C (302°F). Refuse will contain plastics which, in turn, have a chloride component. In the presence of water vapour, which is always present when burning refuse, the chloride will convert to hydrogen chloride gas. When the gas temperature drops below 150°C (302°F), the hydrogen chloride will begin to condense to a liquid, hydrochloric acid which will produce severe corrosion to steel and other metallic surfaces.

High temperature corrosion of steel occurs when hydrogen chloride is present in the flue gas. At temperatures in excess of 370°C (700°F), ferric chloride will form; this compound is friable, i.e., it will form a series of flakes on the steel surface and the surface will "waste" away. As the temperature increases, this type of corrosion will increase significantly.

To reduce dew point corrosion, the exiting flue gas must never be allowed to drop too low in temperature. This is particularly important when an economizer or an air preheater is used to try to extract relatively low level heat from the flue gas.

Control of high temperature corrosion is more difficult. By generating steam at a temperature less than 370°C (700°F), the incidence of high temperature corrosion will be greatly reduced (the temperature of the steel boiler tubes is essentially equal to the temperature of the generated steam). The concentration of hydrogen chloride in flue gas is highest just above the grate. To further reduce the corrosion potential of the flue gas, the lower section of waterwall is normally coated with a refractory material with heat conduction properties, such as carbide brick or cement.

When superheated steam is desired, with temperatures in excess of 370°C (700°F), superheater sections should be placed as far as possible from the burning waste, downstream or immediately upstream of the boiler convection section. By the time the flue gas reaches this area of the incinerator, there should have been sufficient mixing by virtue of the turbulent upstream conditions to reduce the occurrence of concentrated pockets of hydrogen chloride. The hydrogen chloride should be fairly evenly distributed through the gas stream, resulting in a relatively low concentration.

Guideline. Central waste incinerators should meet all the aspects of Polices 01-01 and 01-03 as well as the other aspects discussed in Section 4.1.2. It should be noted that the calculation of residence time for these units must be determined by an overall design review.

4.2.2 Semi-Suspension Incineration

Equipment Description. Semi-suspension incineration differs from mass burning in that the waste is pretreated to produce a finer, more homogeneous material, commonly referred to as refuse-derived-fuel or RDF. The pretreatment steps normally include shredding and ferrous metal recovery by magnetic separation, and can include air classification for removal of other non-combustible material (e.g., non-ferrous metal and glass).

The RDF is blown into the furnace through a pneumatic charging system. Primary combustion (of approximately 70% of the waste's combustible content) occurs in suspension. Ash and unburned material drop onto a travelling grate where final burnout occurs. The grate discharges the ash to a hopper for removal to final disposal.

The high degree of turbulence in the furnace contributes to high ash carryover in the flue gas stream, necessitating the installation of higher efficiency particulate removal equipment with this type of incinerator than with mass burn units.

Application. Semi-suspension burning is suitable for the destruction of RDF as well as other materials requiring agitation, or turbulence, for effective combustion (e.g. powdered carbon, sawdust, etc.). It also permits the reclamation of recyclable materials. In Ontario, a semi-suspension incineration system for RDF is located in the City of Hamilton (SWARU).

Development Status. Although semi-suspension incineration systems are commercially available, they have not gained the widespread acceptance that mass-burning systems currently enjoy, largely due to the additional complexity and cost associated with waste preparation. They do, however, allow the reclamation of salvageable materials from the waste stream, which has been recognized by the Provincial and Federal governments to be a desirable activity.

Operating Practice. These systems require waste pre-processing which, at a minimum, includes shredders and magnetic separators (see Section 3.1.4). Although the heating value of the RDF generated by these processes can be 20% higher than the specific heating value of Municipal Solid Waste (MSW), production of this fuel requires a significant investment in capital equipment and high operating costs. Likewise, system reliability is generally lower than mass burn systems because of the greater amount of process equipment.

Guideline. Semi-suspension incinerators should meet all the aspects of Policy 01-01 and 01-03 as well as the other aspects discussed in Section 4.1.2. It should be noted that the calculation of residence times for these units is particularly complex and must be determined by an overall design review.

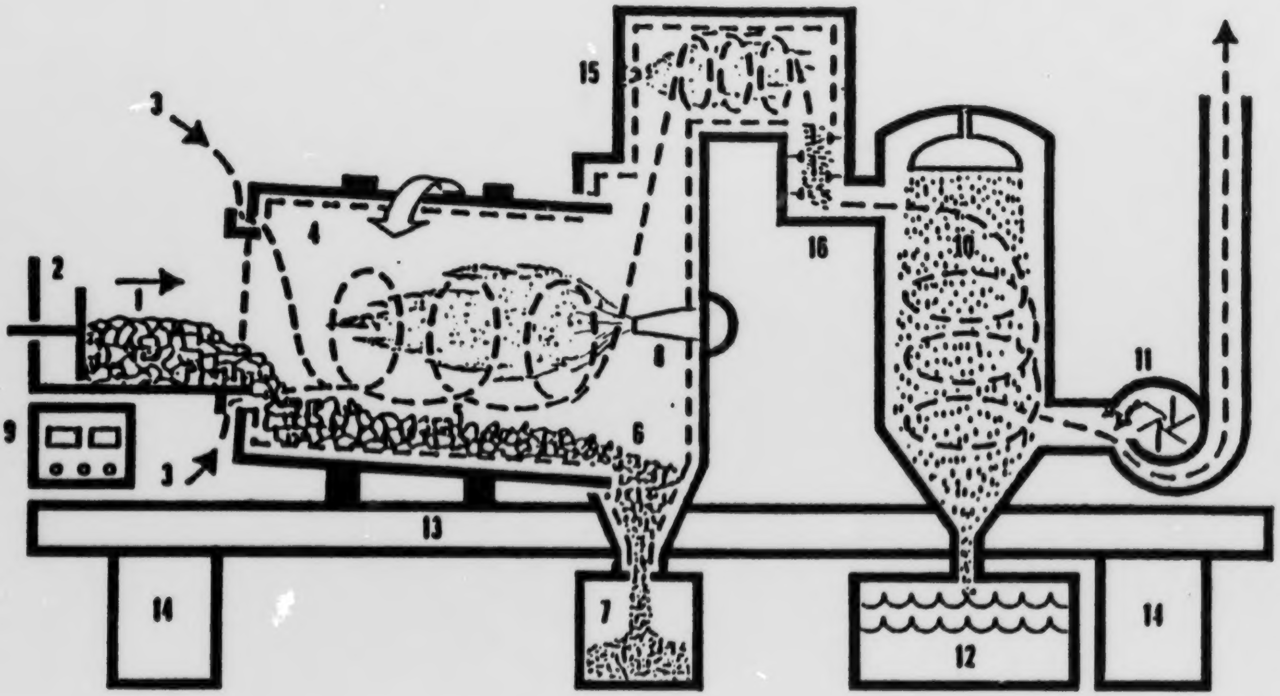
4.2.3 Rotary Kiln Incineration

Equipment Description. The rotary kiln is the most flexible and versatile of the incinerators in common use today. As shown in Figure 4-16, it is a horizontal, refractory-lined structure that rotates about its horizontal axis. Waste is fed from one end and, through the action of the rotating chamber, moves toward the other end of the kiln. Burners for startup and provision of a supplementary source of heat can be mounted on either end of the kiln. The kiln is sized and operated so that by the time the waste material reaches the end of the kiln, it has burned out to an ash that falls into a hopper for removal and disposal.

The kiln is mounted at a slight angle to the horizontal, which is referred to as its rake. By varying the rake and the speed of rotation, the waste retention time within the unit can be varied.

Afterburner sections are required to ensure complete burnout of the off-gases.

Application. The rotary kiln system is highly versatile as it is capable of burning solids, sludges, liquids, and gases. Solids are typically ram-fed or dropped by conveyor onto the kiln hearth, while sludges, liquids, and gases are injected through nozzles located in the front or rear face of the kiln or in the afterburner. They are particularly attractive for the destruction of toxic or hazardous wastes due to their ability to operate at temperatures in



1 Waste to incinerator
2 Auto-cycle feeding system: feed hopper, pneumatic feeder, slide gates
3 Combustion air in
4 Refractory-lined, rotating cylinder
5 Tumble-burning action
6 Incombustible ash
7 Ash bin
8 Auto-control Burner Package: programmed pilot burner
9 Self-compensating instrumentation-controls
10 Wet-Scrubber Package: stainless steel, corrosion-free wet scrubber; gas quench
11 Exhaust fan and stack
12 Recycle water, fly-ash sludge collector
13 Support frame
14 Support piers
15 Afterburner chamber
16 Precooler

Figure 4-16
ROTARY KILN

excess of 1400°C (2550°F) when fitted with an afterburner.

Development Status. Rotary kiln incinerators are commercially available in diameters of approximately 1 m and greater, and have even been constructed as portable, trailer-mounted units. They have been used by industry, municipalities, and the military to destroy combustible liquid, solid, and gaseous wastes. The 3M Company in London, for instance, is installing a rotary kiln incinerator to dispose of solid and gaseous wastes from its manufacturing processes.

Operating Practice. The length to diameter ratio for rotary kilns varies from 2:1 to 10:1. They are usually mounted at a rake of less than 2 to 3% with a variable rotational speed normally in the range of 0.25 - 1.5 rpm.

Residence time of solids and sludges is a function of kiln dimensions, rake, and rotational speed, and is varied with the type of waste being incinerated. Liquids are normally fired in suspension. Residence time can range from seconds for liquids and gases to hours for solids. Excess air of approximately 100% of the stoichiometric requirement is normally required to assure effective incineration, although some manufacturers have designed kilns for operation at substoichiometric conditions.

Similarly, combustion temperatures vary according to the waste characteristics. Temperatures within the kiln are generally limited to less than 1000°C (1832°F), but afterburners may operate as hot as 1650°C (3000°F). Kilns have been developed that are maintained at temperatures in excess of 1300°C (2370°F) to allow a pool of molten slag to form. These slagging kilns are used when charging a metal drum or when the waste has a significant inorganic content.

Generally the temperature in the kiln itself is maintained high enough to release volatiles from the waste. Destruction of these volatiles normally is assured in the afterburner. Rotary kiln systems are applicable to solid, liquid, and gaseous waste; however, solid waste must generally be sized to fit within the kiln charging system.

Wastes containing salts are generally not applicable for destruction in a conventional rotary kiln system. Salts will likely be molten at incinerator temperatures, forming a cake or severe slagging where system temperatures drop (in the air emission control train, for instance) below the salt melting temperature. Slagging kilns can be used for wastes containing salts.

In many instances, placing drums of waste directly into a kiln has led to problems of rapid burning or explosions. Even when the drum is cut and quartered, waste adjacent to the drum shell can heat up faster than exposed waste, creating the potential for a conflagration.

Kiln seals present design problems. The kiln seal must fit tight against the moving kiln surface which is uneven and is not necessarily turning true. In addition to this erosive service, the seal must withstand high temperatures radiating from the kiln interior. The kiln seal design should be carefully evaluated for optimal service.

Guideline. Rotary Kiln incinerators. Should always be run at a negative pressure (draft) to prevent external leakage of hot flue gas, as well:

- A rotary kiln used for waste disposal should include provisions for adjustment of rake.

- In addition, the kiln drive should be infinitely variable throughout its range.

4.2.4 Biomedical Waste Incineration and Cremators

Volume 2 of this criteria document discusses biomedical waste incineration in detail, and Volume 3 addresses cremator equipment.

Equipment Description. Three types of incinerators have been used for the incineration of biomedical waste:

- Multiple chamber
- Controlled air
- Rotary kiln

A cremator is a double chamber incinerator into which is charged a casket and its contents.

Additional Guideline for Biomedical Waste Incinerators. The incinerator must be designed to prevent leakage of liquids that may be contained in the waste. All feed systems shall be sloped toward the opening of the incinerator. Provisions should be included within the incinerator system for disinfecting the hopper sides and the charging containers. The maximum heat release rate should be 400 000 kJ/h/(h-m^3) [12,000 Btu/(hr-ft^3)] in the primary chamber and 836 000 kJ/(h-m^3) [25,000 Btu/(hr-ft^3)] in the secondary chamber. A solid hearth should be provided to hold the charged waste, and the hearth burning rate should be no greater than 68.5 kg/(hr-m^2) [14 lb/(hr-ft^2)]. The temperature of the primary chamber should be maintained in the range of 400°C to 760°C (750°F to 1400°F). At least two burners should be provided for incinerators rated at 100 kg/h (220 lb/hr) or greater.

Additional Guidelines for Cremators. The primary chamber should be maintained at a minimum temperature of 800°C for at least 30 minutes during the last part of the cycle to ensure complete calcination and sterilization.

4.2.5 Multiple Hearth Systems

Equipment Description. This is a vertical cylindrical structure, refractory-lined, with a series of refractory hearths positioned one beneath the other, as shown in Figure 4-17.

The centre shaft, which is hollow to allow the passage of cooling air through it, rotates within the incinerator at approximately one revolution per minute carrying the rabble arms with it sweeping waste across the hearths. The waste is rabbled from the edge of one hearth to its centre, and drops to the next hearth where it is rabbled to the outside of that hearth, and so on. Alternate hearths have large centre openings or outside drop holes through which the waste falls.

The furnace is particularly well suited to the combustion of sludge, which is dried on the top hearths and starts to burn toward the centre of the furnace. It burns out to ash at the bottom of the furnace where it is discharged.

Application. Multiple hearth incinerators are designed to burn wastes with low heating value such as sewage sludge and other high-moisture-content wastes. Its design includes drying as well as burning sections. Materials with less moisture content, such as coal or solid waste, will start to burn too high in the furnace. There would be insufficient residual time in these cases for effective burnout.

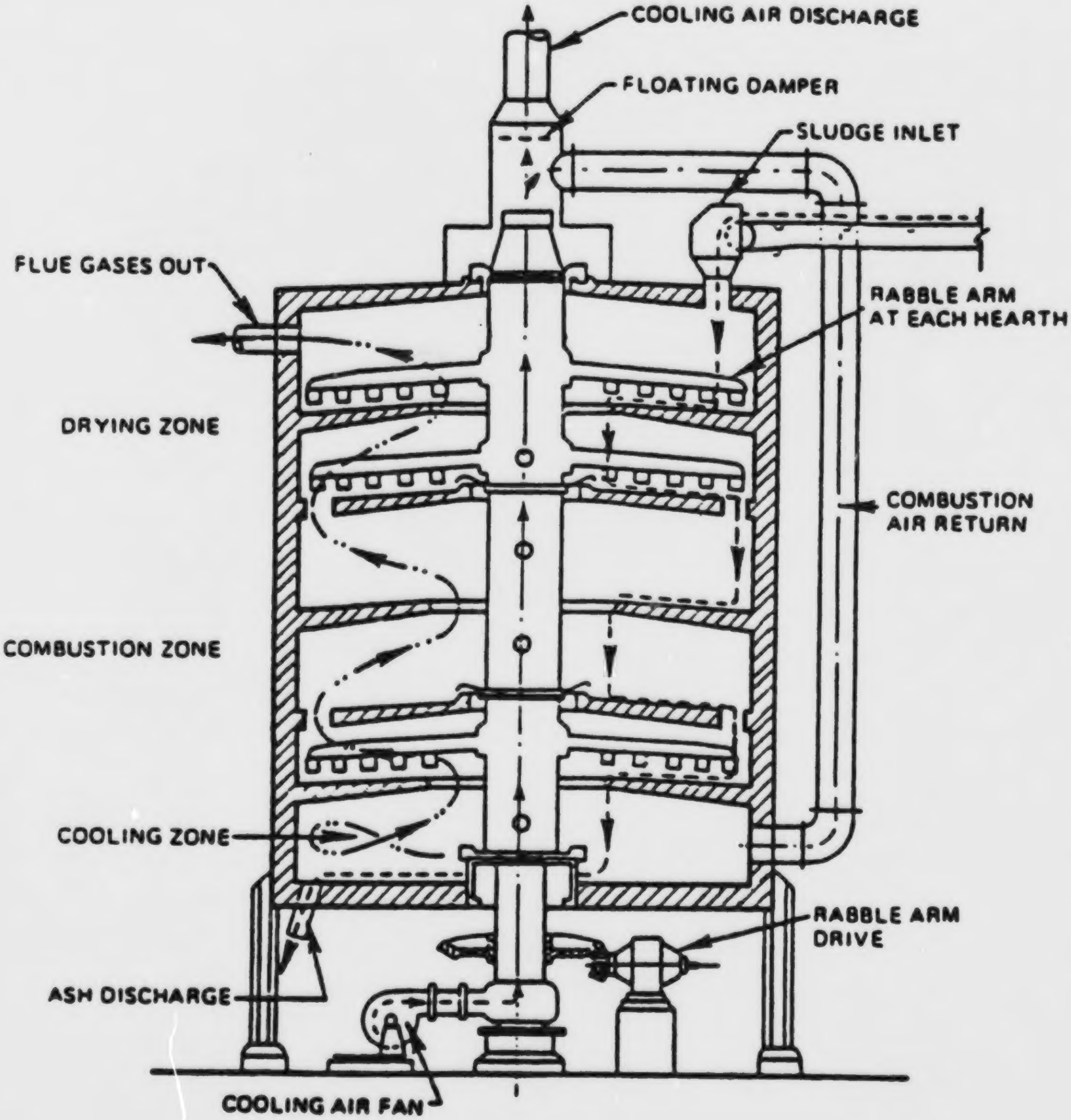

COOLING AIR DISCHARGE
FLOATING DAMPER
SLUDGE INLET
FLUE GASES OUT
RABBLE ARM AT EACH HEARTH
DRYING ZONE
COMBUSTION AIR RETURN
COMBUSTION ZONE
COOLING ZONE
RABBLE ARM DRIVE
ASH DISCHARGE
COOLING AIR FAN

Figure 4-17

MULTIPLE HEARTH INCINERATOR

This incinerator system is relatively complex with fans, burners, shaft speed, and feed charging all within the operator's control, and all affecting combustion efficiency and burnout. Particular attention must be paid to operator training in the proper control of these various equipment items and parameters.

Development Status. This is the most prevalent incineration system for sewage sludge destruction in North America. Several multiple hearth incinerators are being used to burn sewage sludge in Toronto, Ontario.

Operating Practice. Multiple hearth furnaces range from 2 to 8 m (6.6 to 26.2 ft) in diameter and from 4 to 23 m (13 to 76 ft) in height. The number of hearths is dependent upon the waste feed and processing requirements, but generally varies between 5 and 12 hearths. Waste retention time is controlled by the rabble tooth pattern and the rotational speed of the central shaft.

The upper hearths of the furnace comprise the drying zone where moisture is evaporated from the sludge. Flue gas exits this upper zone of the incinerator at 430°C to 650°C (806°F to 1202°F). In the centre hearths, the combustion zone, temperatures are normally in the 760°C to 980°C (1400°F to 1796°F) range. Cooling air exiting the top of the centre shaft is approximately 90°C to 230°C (194°F to 446°F), and is often recirculated to the furnace as preheated combustion air.

Where sludge contains grease or other volatile components, an afterburner may be required for effective burnout, i.e., elimination of smoke and odour. The maximum off-gas temperature from the incinerator is below 700°C (1291°F). If higher temperatures are required, a separate afterburner must be provided. The afterburner can be an expanded top hearth or it can be provided as a separate piece of equipment.

Excess air of 100-125% must be provided to ensure complete burnout of the sludge to ash. Since approximately 20% of the ash can be entrained in the flue gas, extensive gas-cleaning equipment must be provided for its capture (see Chapter 6 for a discussion of air emissions control equipment).

This incinerator will handle sludges in the range of 50 to 85% moisture. It is generally not applicable to the incineration of solid materials.

The multiple hearth furnace is a flexible piece of equipment. There is a limitation in the sludge consistency that it can process (generally from 15 to 50% solids content) but the nature of the sludge is not necessarily limiting as with, for instance, the fluid bed furnace. Another feature of the multiple hearth furnace is that it has a relatively constant fuel use curve, i.e., the use of fuel is directly proportional to the amount of sludge burned, its moisture and combustible content, and its heating value. If the sludge feed is doubled, the fuel required to incinerate the sludge is doubled. This is not necessarily true with other types of incinerator systems, such as the fluid bed incinerator.

Ash exits this system dry from beneath the furnace. It can be collected and disposed of dry, or it can be dropped into a wet hopper, mixed with water, and pumped to a lagoon for dewatering and ultimate disposal.

Feeding a multiple hearth is relatively simple. Feed can be dropped onto the top hearth by gravity. It can also be deposited on the top hearth or a lower hearth by means of a screw conveyor. Attempts to feed sludge to a multiple hearth furnace pneumatically have met with failure. This system necessarily injects air into the furnace in strong discrete bursts which makes maintenance of constant furnace draft difficult, if not impossible.

There are a number of disadvantages in the use of this equipment. Generally, the multiple hearth furnace cannot accommodate a temperature in excess of 1000°C (1830°F) without damage. If higher temperatures are required, an afterburner must be provided, which represents higher capital costs and higher operating (fuel) costs.

It is virtually impossible to maintain heat in a multiple hearth furnace without firing supplemental fuel. This furnace, as noted above, has many areas of leakage and, therefore, heat cannot be effectively maintained within the units as in, for example, a fluid bed furnace.

Fuel or gas can be used as supplemental fuel. Generally solid fuels, such as coal or wood chips, should not be placed on a hearth and used as supplemental fuel. They are relatively dry and will start burning on the top hearth, encouraging premature release of volatiles from the waste stream and inadequate burnout can result.

Guideline. Sludge or other wastes deposited on the hearth of a multiple hearth furnace should have a solids content of 15 to 40% for proper movement and rabbling through the furnace. The temperature above at least two hearths should be maintained at approximately 870°C (1600°F) at all times when burning sludge cake. The off-gas temperature can range from 425°C to 760°C (800°F to 1400°F).

Generally, grease (scum) should not be added to sludge feed. If grease is to be incinerated in the multiple hearth furnace it should be added at a lower hearth (a burning hearth) through a separate nozzle(s). Grease will volatilize easily and introducing it too high in the furnace where the temperatures may be below 760°C (1400°F) will not provide effective burnout.

Air emissions control equipment should be provided to reduce particulate emissions.

Dry solids or solid fuels should not be fed to a multiple hearth furnace. Exceptions may be considered if the solids are added beneath the drying zone in the burning zone of the furnace.

The oxygen content of the flue gas exiting the furnace should be continuously measured at the breeching leaving the top hearth. A sample should be continuously extracted from the gas stream, passed through a water bath to clean the sample and to reduce its moisture content, and then measured for oxygen content. The oxygen content should be in the range of 6 to 10% by volume.

In general, industrial waste liquids and gases should not be introduced into the multiple hearth incinerator itself. They should be fired in a separate afterburner immediately downsteam of the incinerator.

The multiple hearth furnace should always be run at a negative pressure (draft) to prevent external leakage of hot flue gas. If a separate afterburner is needed and if an emergency discharge stack is provided, the stack should be located downstream of the afterburner.

4.2.6 Fluidized Bed Incinerators

Equipment Description. As illustrated in Figure 4-18, the fluid bed furnace is a cylindrical, refractory-lined shell with a porous plate elevated to support a bed of inert material. Preheated air is introduced through the windbox, beneath the plate, and passes upwards through openings in the plate, fluidizing the sand bed.

Waste is fed into or on top of the bed, which is normally maintained at a temperature of 760°C to 870°C (1400°F to 1600°F) by auxiliary burners located either above or below the bed. Moisture in the waste flashes to steam almost instantaneously. The organics are burned within the bed or in the freeboard zone above the bed. Ash will either exit the incinerator in the exhaust gas or it will build up within the bed. Virtually all of the residual ash when burning sewage sludge is elutriated from the bed and entrained in the flue gas stream. This heavy fly ash loading must be removed in downstream particulate removal equipment.

Application. Fluid bed furnaces have been used for combustion of many materials, including coal, coke, wood, oil sands, and several other fuels. In incineration applications, fluidized bed systems have been used principally for the combustion of sludges, particularly sewage sludge. A prime requisite for the successful combustion of solid waste is that it be adequately prepared by shredding and sorting.

The only application of fluid bed incineration to solid waste in North America is in Minnesota where solid waste and sludge have been incinerated in the same unit. This installation has experienced many technical problems.

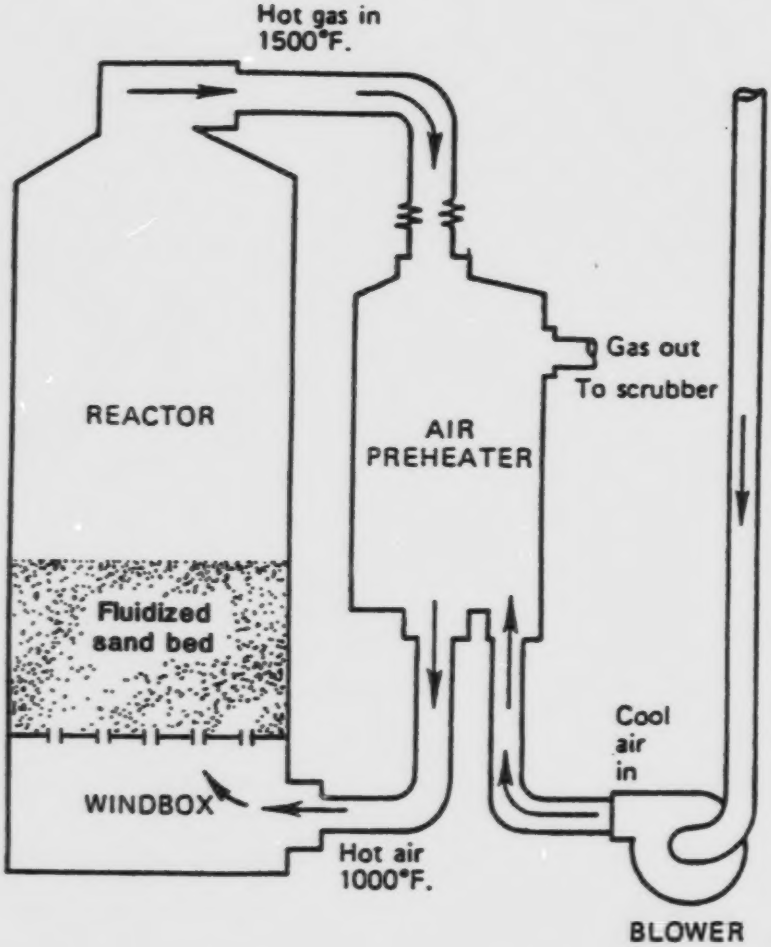

Hot gas in
1500°F.
Gas out
To scrubber
REACTOR
AIR
PREHEATER
Fluidized
sand bed
Cool
air
in
WINDBOX
Hot air
1000°F.
BLOWER

Figure 4-18
FLUIDIZED BED SYSTEM

The presence of heavy, non-combustible materials in the waste may cause the bed volume to increase with time, necessitating that it be tapped to prevent excessive agglomeration.

Development Status. Fluidized bed technology has been employed in several industries for many years. The first fluid bed used for incineration of sewage sludge was in 1962. Since that time it has been gaining popularity in North America. In Canada, fluidized bed incinerators are used at Pickering and Mississauga, Ontario, to dispose of sewage sludge.

Operating Practice. The bed material is most commonly silica sand, but may also be comprised of limestone, alumina, or ceramic material. The bed expands from 30 to 60% in volume when fluidized with air at a velocity of approximately 0.5 to 1.5 m/s (1.5 to 4.5 ft/sec).

Excess air requirements are low, usually only from 40 to 60%. Residence time is determined by bed depth, freeboard above the bed, and the fluidizing velocity, and is selected based on the characteristics of the waste being burned.

The fluid bed furnace system is compact, of airtight construction, and with most manufacturers, is maintained as a positive pressure system. By maintaining the entire system under positive pressure, the furnace must be designed to be airtight. This feature is useful in applications where the furnace is called upon to operate on a non-continuous basis. If the furnace is to operate five days per week, for instance, its airtight construction allows it to be sealed fairly effectively. Dampers on its inlet and outlet will hold in its heat and the refractory and sand within the unit provide significant thermal inertia. As a result of its construction the fluid bed furnace after a shutdown will lose as little as 5°C (9°F) per hour. It can be shut down on a Friday evening and will require only a few hours of heat-up on a Monday morning to be available for waste feeding.

The fluid bed furnace has few moving parts. Its major area of maintenance is the recuperator, or gas-to-air tube-in-shell heat exchanger that is usually provided with this equipment. This equipment is sensitive to temperature and is generally limited to a sustained operating temperature of 900°C (1650°F). Above this temperature severe corrosion will occur, reducing the heat exchanger tube wall dimension to the point of weakness and subsequent failure. Oxygen present in the flue gas will de-carburize carbon steel at temperatures in excess of 900°C (1650°F), producing the indicated corrosive effect. Other incinerator heat exchanger designs, particularly insertion type units such as the ones of European manufacture, use an intermediate heat exchange medium such as heated oil, hot water or steam, and the effect of the high incinerator off-gas temperatures is not as significant as with the tube-in-shell exchanger.

An internal water spray system is often employed in fluid bed systems to help protect the heat exchanger from temperature excursions. Water is automatically injected into the freeboard when the heat exchanger inlet temperature is above a pre-set figure, perhaps 870°C (1600°F).

A fluid bed furnace requires a minimum amount of air to maintain bed fluidization, regardless of the waste feed. The fluidizing air requirement is based on the furnace rating. When the bed is operating at a feed below the design point, approximately the same air quantity is required as is required at design to maintain fluidization. This results in a unit that may have good fuel consumption at its design point, but has a relatively high fuel consumption at lesser feeds.

While ash from a fluid bed furnace normally exits with the flue gas, the ash from some materials when burned will not be airborne but will build up in the bed, requiring periodic bed tapping. Provisions should be included within the fluid bed system to accommodate excessive bed build-up.

Where all of the ash does exit with the flue gas (plus some of the bed sand), the air emissions control system must be designed to remove this load from the gas stream. As a result, high energy scrubbing systems with higher pressure drops than other sludge incineration systems are required.

Feeding of a fluid bed furnace requires particular attention. Except for certain European furnaces in which negative pressure is maintained in the freeboard and where waste can be dropped into the furnace by gravity, most fluid bed furnaces are under positive pressure. Waste must be forced into the furnace, and gravity feed cannot be used. Positive displacement pumps are normally used for feeding fluid bed furnaces. Hard piping should be used from the pumps to the furnace and a purge system should be included to help prevent caking of the piping when not in use.

A major issue associated with a fluid bed furnace is its ability to handle a wide variety of waste streams. It is sensitive to waste composition. Certain wastes, particularly those containing clays, inorganics (salts), or high quantities of lime, will tend to seize the bed, preventing fluidization. Test burns on materials that have not previously been fired in a fluid bed furnace must be performed to determine the bed reaction to those particular materials. If bed seizure does occur, bed additives may be available to help eliminate this problem by changing the physical properties of the waste feed. If not, a fluid bed unit may not be the one to use. A related issue is agglomeration. Waste materials may build up on individual sand particles within the bed. With changes in operation (such as maintaining a higher bed residence time) this could be controlled. If not addressed, agglomeration could result in bed seizure.

It has been found that natural gas will not necessarily burn well within a fluid bed. It will tend to pass vertically through the bed without mixing within the sand. It can be fired in a windbox beneath the sand bed, however, without this concern.

Guideline. Sludge, liquids, and prepared solid waste can be fed directly to the bed of the fluid bed reactor. Sludges with a moisture content in excess of 80% and aqueous liquids with high water contents can be fed in the top of the furnace at the furnace ceiling rather than into the bed. Top injection tends to reduce the bed area otherwise required for sludge moisture evaporation.

The temperature within the bed should be maintained at approximately 760°C (1400°F) for organic sludges. The use of sludges or other wastes containing inorganic materials should be subject to a test burn before injecting into a fluid bed furnace.

The freeboard should be maintained in the range of 760°C to 870°C (1400°F to 1600°F). This temperature should never be allowed to exceed 870°C (1600°F) when a heat exchanger is used, unless the heat exchanger is specifically designed for operation at a higher gas inlet temperature. Water sprays should be provided at the ceiling of the furnace for cooling the gas stream if its temperature approaches 870°C (1600°F).

Gaseous waste or fuel should not be injected into the bed. It can be fired in the windbox.

The oxygen content of the flue gas exiting the furnace should be continuously measured at the breeching leaving the furnace upsteam of the recuperator (if one is provided). A sample should be continuously extracted from the gas stream, passed through a water bath to clean the sample and to reduce its moisture content, and then measured for oxygen content. The oxygen content should be in the range of 4 to 8% by volume, on a dry basis.

In general, industrial waste liquids and gases should not be introduced into a fluid bed incinerator if they require a temperature in excess of 870°C (1600°F) for destruction. The air heater normally provided with these systems cannot withstand greater than 870°C (1600°F) inlet gas temperature. An afterburner is normally not provided for a fluid bed incinerator system.

4.2.7 Liquid Injection Furnaces

Equipment Description. For purposes of incinerator design, a material is considered a liquid if it can be pumped to a burner, atomized, and fired in suspension. Liquid injection incinerators are either horizontally or vertically oriented, cylindrical, refractory-lined chambers fitted with nozzles firing axially or tangentially into the furnace. Several types of atomizing nozzles and burners are used to achieve vapourization of the waste and efficient air/fuel mixing, including fixed orifice nozzles, rotary cup burners, two-fluid burners, and sonic nozzles.

Primary combustion air is normally injected into the waste nozzle with compressed air or steam to promote atomization, while secondary air is introduced downstream of the nozzles to increase turbulence, cool the refractory wall, and control combustion. A typical liquid waste incinerator is illustrated in Figure 4-19.

Applications. Liquid injection incinerators can be used to dispose of almost any combustible liquid waste, including lubrication oils, paints, solvents, and pesticides. With appropriate nozzle design, liquids with kinematic viscosities of up to 1.62×10^{-4} m^2/s (750 SSU) can be fired in suspension.

Development Status. A wide variety of liquid injection incinerators are marketed today, and these represent probably the most common incinerator type for hazardous waste disposal. In Ontario, Tricil Limited in Corunna and Dow Chemical Canada Inc. in Sarnia operate liquid injection incinerators for destruction of liquid industrial wastes. In the United States, ship-mounted, liquid injection incinerators are seeking permits for test burns for disposal of hazardous materials at sea.

Operating Practice. Liquid injection furnaces typically require 15-30% excess air and operate at retention times in the range of 0.5 to 2 seconds. Operating temperatures vary from 650°C to 1650°C (1200°F to 3000°F), but are normally around 870°C (1600°F), depending on waste destruction characteristics.

Liquid waste can be injected within the flame front if its heating value is high enough to add to the net heating

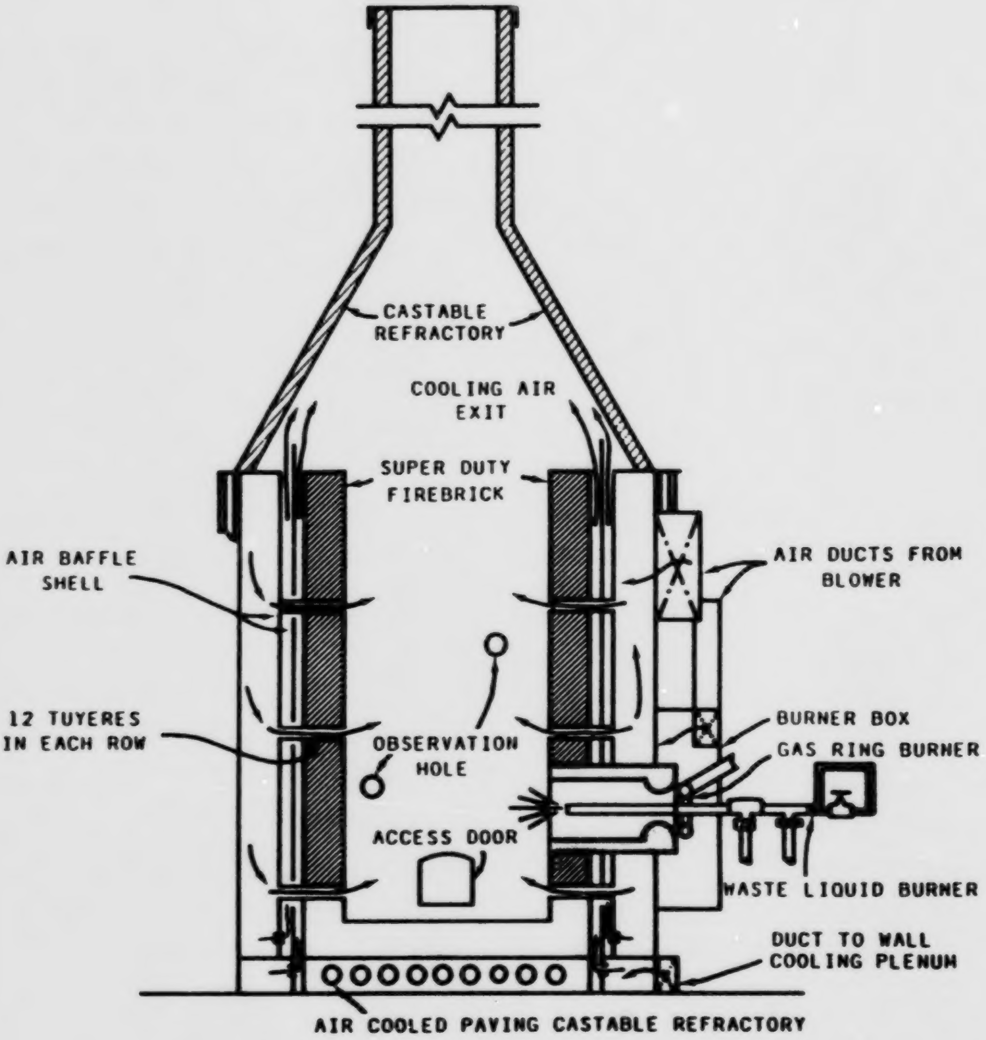

CASTABLE REFRACTORY
COOLING AIR EXIT
SUPER DUTY FIREBRICK
AIR BAFFLE SHELL
AIR DUCTS FROM BLOWER
12 TUYERES IN EACH ROW
OBSERVATION HOLE
BURNER BOX
GAS RING BURNER
ACCESS DOOR
WASTE LIQUID BURNER
DUCT TO WALL COOLING PLENUM
AIR COOLED PAVING CASTABLE REFRACTORY

Figure 4-19
LIQUID WASTE INCINERATOR

value of the flame (i.e., greater than approximately 11 600 kJ/kg [4987 Btu/lb]). Aqueous or other low heating value waste is normally injected outside the flame envelope.

Conventional liquid waste incinerators may not be able to handle wastes containing inorganic salts. Salts will be molten at temperatures in the range of 760°C to 870°C (1400°F to 1600°F) and can condense downstream of the firing chamber to form slag. Specialty liquid waste incinerators have been developed specifically for incineration of salt-laden wastes; they maintain salt in a fluid state and quench the molten salt in a water bath.

The types of nozzle used will often have a significant impact on the design of the furnace, and can be chosen to prevent flame impingement. Following is a discussion of nozzle types used with liquid waste streams.

Mechanical Atomizing Nozzles. These are the most common types of burner nozzles in current use. Fuel is pumped into the nozzle at pressures of 515-1030 kPa (75-150 psig) through a small fixed-orifice discharge. The fuel is given a strong cyclonic or whirling velocity before it is released through the orifice. Combustion air is provided around the periphery of the conical spray of fuel produced. The combination of combustion air introduced tangentially into the burner and the action of the swirling fuel produce effective atomization. Normal turndown ratios are in the range of 2.5:1 to 3.5:1. By utilizing a return flow line for fuel oil, the turndown ratio can be increased to as high as 10:1. A major disadvantage of this type of burner/nozzle is its susceptibility to erosion and pluggage from solids components of the fluid stream. Flames tend to be short, bushy, or low velocity, and this results in slower combustion, requiring relatively large combustion chamber volumes. This burner is applicable for fluids with relatively low kinematic viscosity, under .22 x 10^{-4} m^2/s (100 SSU).

Rotary Cup Burners. Atomization is provided by throwing fuel centrifugally from a rotating cup or plate. Oil is thrown from the lip of the cup in the form of conical sheets which break up into droplets by the effect of surface tension. No air is mixed with fuel prior to atomization. Instead, it is introduced through an annular space around the rotary cup. Normally a common motor drives the oil pump, rotating cup, and combustion air blower. The liquid pressure required for this burner is relatively low, since automization is a function of cup rotation and combustion air injection, not fuel pressure. This low pressure requirement and the relatively large openings within the burner fuel path allow passage of fluids with relatively high solids contents, as high as 20% by weight. They have a turndown ratio of approximately 5:1 and can fire liquids with kinematic viscosity up to .65 x 10^{-4} m^2/s (300 SSU). Rotary cup burners are sensitive to combustion air flow adjustment. Insufficient air flow will result in fuel impingement on furnace walls, while excessive combustion air will cause a flame-out.

External Low-Pressure Air-Atomizing Burners. The major portion of the combustion air requirement is provided at 7-35 kPa (1-5 psig) near the burner tip. Air is injected externally to the fuel nozzle and is directed to the liquid stream to produce high turbulence and effective atomization. The liquid pressure necessary for operation is only enough for positive delivery, normally less than 10 kPa (1? psig). Secondary combustion air is provided around the periphery of the atomized liquid mixture. The flame is relatively short because of the high amount of air provided at the burner (atomization and secondary combustion air). The short flame allows design of smaller combustion chambers. These burners normally operate with liquids in the range of .43-3.24 m^2/s (200-1500 SSU) and can handle solids concentrations in the liquid of up to 30%. A small quantity of the air flow passes around the fuel discharge to aid in optimization of the fuel flow pattern.

External High-Pressure Two-Fluid Burners. The atomizing fluid, air or steam (or nitrogen or other gas), impinges the fuel stream at high velocity to generate small particles that encourage quick vapourization and effective atomization of tars and other heavy liquids. The required atomization pressure varies from 200 to 1030 kPa (30 to 150 psig). Turndown is in the range of 3:1 to 4:1. The flame produced is relatively long, requiring appropriately constructed combustion chambers. The fuel viscosity normally handled by these burners ranges from .3 to 10.8 m^2/s (150 to 5000 SSU) for either air or steam atomization. A solids content of up to 70% can be accommodated by these burners.

Internal Mix Nozzles. Air or steam is introduced within the nozzle to provide impingement of atomization fluid on the fuel stream prior to spraying. Atomization air is provided at pressures less than 200 kPa (30 psig) and steam is normally introduced at 620-1030 kPa (90-105 psig). The turndown ratio for this type burner is from 3:1 to 4:1. These nozzles cannot tolerate a signficant solids content and can handle only low-viscosity fuels, under .22 m^2/s (100 SSU). This burner is used for clean, low-viscosity liquids. Its advantage is in its low cost compared to other burners.

Sonic Nozzles. These nozzles utilize a compressed gas such as air or steam to create high frequency sound waves which are directed at the fuel stream. This acoustic energy is transferred to the liquid stream and creates an atomizing force, breaking the stream into minute particles. The fuel nozzle diameter is relatively large, allowing passage of solid particulate streams such as slurries and sludges with high particulate content. Little fuel pressurization is required. The spray pattern is not well defined, with finely atomized, uniformly distributed droplets travelling at low velocities. These nozzles are difficult to adjust, have low turndown, and generate an extremely high noise level during operation.

Guideline. The design of the furnace should include provisions to prevent flame impingement on a furnace wall. With flame from either the waste or the supplemental fuel impinging on a wall, the full heating value of the fuel is not realized. The resultant carbonaceous build-up on the wall prevents normal gas flow within the furnace from "washing" the surface and hot spots will develop. In addition, this build-up will eventually result in corrosion of the refractory and increased refractory maintenance.

Liquid waste streams containing in excess of 50 ppmv inorganics may not be appropriate candidates for conventional liquid waste incinerators. Specialty incinerators may have to be used which are designed specifically for this duty.

4.2.8 Gas Incineration

There are basically two methods of gaseous waste destruction, direct flame and catalytic incineration. Direct flame combustion includes flares, fume incinerators, gas combustors, and afterburners. This is the most common method of gas incineration. Catalytic incineration uses catalysts to reduce the temperature required for waste destruction.

4.2.8.1 Direct Flame Incineration

Equipment Description. Direct flame incineration requires bringing a waste gas to an appropriate temperature and holding it there long enough to oxidize the organics to carbon dioxide and water. Flaring is the simplest means of disposing of relatively large quantities of waste gas with combustible components. The gas is ignited and discharged to the atmosphere without heat recovery. The process is particularly suited to the disposal of intermittent gas discharges.

As illustrated in Figure 4-20, a flare is basically a stack discharging a combustible gas to the atmosphere. A pilot flame at the end of the stack ignites the gas, the combustion of which is supported by the surrounding atmosphere. Steam is frequently introduced into the flame to generate turbulence and promote mixing with the surrounding air, to aid in cracking complex molecules, and to help oxidize carbon.

Fume incinerators and gas combustors are chambers equipped with supplemental fuel burners that provide the temperature and residence time necessary for a more controlled combustion of gaseous waste materials. They may be either horizontal or vertical in orientation, although vertical units are not usually suited to heat recovery.

Fume incinerators can be equipped with some means of heat recovery. The hot exhaust gases may be used to preheat the incoming combustion air or waste gas or to heat a stream for external use.

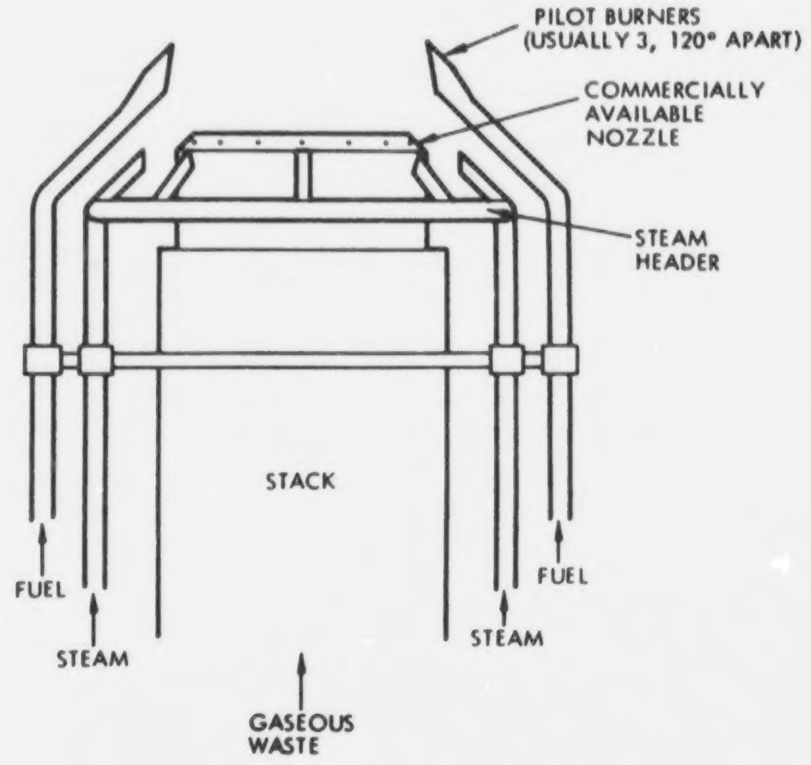

PILOT BURNERS
(USUALLY 3, 120° APART)
COMMERCIALLY
AVAILABLE
NOZZLE
STEAM
HEADER
STACK
FUEL
FUEL
STEAM
STEAM
GASEOUS
WASTE

Figure 4-20
TYPICAL FLARE

Application. Direct flame incineration is best applied to waste gas streams rich in combustible constituents. Probably the most common application of flares is the combustion of waste gases and vent gases from petroleum refining operations. Fume incinerators have been successfully applied to control smoke and solvent emissions from surface coating operations, odourous emissions from food facilities, as well as combustible fumes from a wide variety of industries such as printing, food processing, and chemical processing.

Development Status. Numerous types of flare and direct flame incineration equipment are commercially available for gas combustion.

Operating Practice. Combustion temperatures developed in flare systems normally range from 1100°C to 1400°C (2010°F to 2550°F). However, residence time and air/fuel mix are relatively uncontrolled, frequently resulting in incomplete combustion of the waste gas.

Combustion chamber temperatures in fume incinerators vary from 430°C to 820°C (806°F to 1508°F), depending on the waste constituent, with residence time ranging from 0.5 to 2 seconds.

4.2.8.2 Catalytic Incineration

Equipment Description. Catalytic incinerators are used to destroy the organic components of a gas stream at lower temperatures than that required by direct combustion, thus effecting significant energy savings for wastes containing low concentrations of combustibles.

The waste gas is normally preheated with fired burners and is then passed over a catalyst bed where the oxidation reactions proceed. The catalyst is normally deposited on an inert material with a high surface area.

At the appropriate temperature and residence time with sufficient oxygen present, 85 to 95% destruction of hydrocarbons can be achieved with catalytic incinerators.

A typical catalytic incinerator is illustrated in Figure 4-21.

Application. Catalytic incineration is most applicable to the destruction of gaseous wastes with low concentrations of combustibles. The waste stream must be free of particulates and several other contaminants (e.g. heavy metals, phosphates, arsenic compounds, halogens, sulphur compounds, alumina and silica dusts, iron oxides, and silicones) which can foul the catalyst materials. Table 4-12 lists a number of these catalyst inhibitors and their effect on the process.

Development Status. Although commercially available, catalytic incinerators are not widely used for waste gas destruction.

Operating Practice. Catalytic incinerators normally operate at temperatures below 600°C (1110°F)and residence times of approximately one second. The catalyst section is normally sized to provide a pressure drop no greater than 1 kPa (4 in W.C.). It should not be used unless the gas stream constituents are consistent in analysis and contain neither particulate matter, halogens, nor other contaminants listed above.

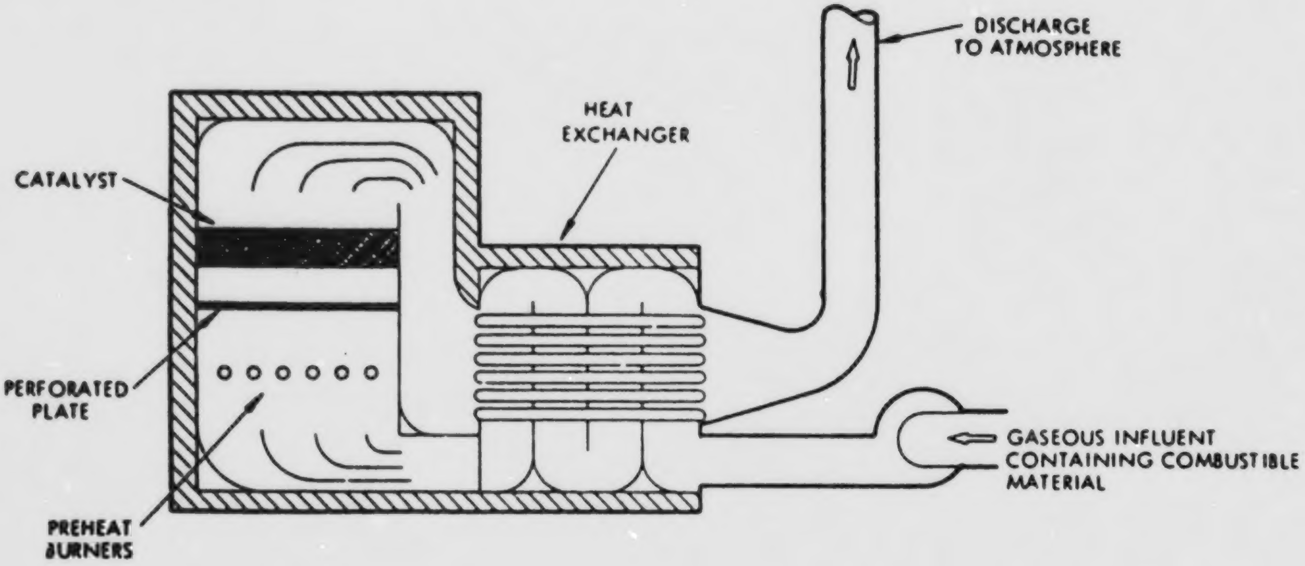

DISCHARGE TO ATMOSPHERE
HEAT EXCHANGER
CATALYST
PERFORATED PLATE
PREHEAT BURNERS
GASEOUS INFLUENT CONTAINING COMBUSTIBLE MATERIAL

Figure 4-21
CATALYTIC INCINERATOR

Table 4-12
Catalyst Inhibitors

Type of Inhibitor	Effect
Fast-Acting Inhibitors Phosphorous, Bismuth, Lead, Arsenic, Antimony, Mercury	Irreversible reduction of catalyst activity at rate dependent on concentration and temperature.
Slow-Acting Inhibitors Iron, Tin, Silicon	Irreversible reduction of catalyst activity. Higher concentrations than those of fast-acting catalyst inhibitors may be tolerated.
Reversible Inhibitors Sulphur, Halogens, Zinc	Reversible surface coating of catalyst active area. Removed by increasing catalyst temperature.
Surface Eroders and Maskers Inert Particulate	Surface coating of catalyst active area. Also errosion of catalyst surface at rate dependent on particulate size, grain loading, and gas stream velocity.

4.2.8.3 Guideline

Flares or direct flame incinerators can be used with gases above the upper explosive limit (UEL) or below the lower explosive limit (LEL). Catalytic incinerators operate most efficiently when the gas stream concentration is no more than 25% of the LEL. The LEL is the lowest concentration of a gas in air that will sustain combustion. The UEL is that concentration above which there is insufficient air present to sustain combustion. Table 4-13 lists LEL and UEL values for common compounds.

Supplemental fuel for flares is required when the gas heating value is less than 5600 kJ/Nm^3 (150 Btu/SCF).

Table 4-13
Combustibility Characteristics of Pure Gases and Vapours in Air

Gas or Vapour	Lower Limit, % by Volume	Upper Limit, % by Volume
Acetaldehyde	4.0	57.0
Acetone	2.5	12.8
Acetylene	2.5	80.0
Allyl alcohol	2.5	-
Ammonia	15.5	26.6
Amyl acetate	1.0	7.5
Amylene	1.6	7.7
Benzene (bensol)	1.3	6.8
Benzlyl chloride	1.1	-
Butene	1.8	8.4
Butyl acetate	1.4	15.0
Butyl alcohol	1.7	-
Butyl cellosolve	-	-
Carbon disulfide	1.2	50.0
Carbon monoxide	12.5	74.2
Chlorobenzene	1.3	7.1
Cottonseed oil	-	-
Cresol, m- or p-	1.1	-
Crotonaldehyde	2.1	15.5
Cyclohexane	1.3	8.4
Cyclohexanone	1.1	-
Cyclopropane	2.4	10.5
Cymene	0.7	-
Dichlorobenzene	2.2	9.2
Dichloroethylene (1,2)	9.7	12.8
Diethyl selenide	2.5	-
Dimethyl formamide	2.2	-
Dioxane	2.0	22.2
Ethane	3.1	15.5
Ether (diethyl)	1.8	36.5
Ethyl acetate	2.2	11.5
Ethyl alcohol	3.3	19.0
Ethyl bromide	6.7	11.3
Ethyl cellosolve	2.6	15.7
Ethyl chloride	4.0	14.8
Ethyl ether	1.9	48.0
Ethyl lactate	1.5	-
Ethylene	2.7	28.6
Ethylene dichloride	6.2	15.9
Ethyl formate	2.7	16.5
Ethyl nitrite	3.0	50.0
Ethylene oxide	3.0	80.0
Furfural	2.1	-
Gasoline (variable)	1.4-1.5	7.4-7.6
Heptane	1.0	6.0
Hexane	1.2	6.9

Table 4-13 (cont'd)

Gas or Vapour	Lower Limit, % by Volume	Upper Limit, % by Volume
Hydrogen cyanide	5.6	40.0
Hydrogen	4.0	74.2
Hydrogen sulfide	4.3	45.5
Illuminating gas (coal gas)	5.3	33.0
Isobutyl alcohol	1.7	-
Isopentane	1.3	-
Isopropyl acetate	1.8	7.8
Isopropyl alcohol	2.0	-
Kerosene	0.7	5.0
Linseed oil	-	-
Methane	5.0	15.0
Methyl acetate	3.1	15.5
Methyl alcohol	6.7	36.5
Methyl bromide	13.5	14.5
Methyl butyl ketone	1.2	8.0
Methyl chloride	8.2	18.7
Methyl cyclohexane	1.1	-
Methyl ether	3.4	18.0
Methyl ethyl ether	2.0	10.1
Methyl ethyl ketone	1.8	9.5
Methyl formate	5.0	22.7
Methyl propyl ketone	1.5	8.2
Mineral spirits No. 10	0.8	-
Naphthalene	0.9	-
Nitrobenzene	1.8	-
Nitroethane	4.0	-
Nitromethane	7.3	-
Noane	0.83	2.9
Octane	0.95	3.2
Paraldehyde	1.3	-
Paraffin oil	-	-
Pentane	1.4	7.8
Propane	2.1	10.1
Propyl acetate	1.8	8.0
Propyl alcohol	2.1	13.5
Propylene	2.0	11.1
Propylene dichloride	3.4	14.5
Propylene oxide	2.0	22.0
Piridine	1.8	12.4
Rosin oil	-	-
Toluene (toluol)	1.3	7.0
Turpentine	0.8	-
Vinyl ether	1.7	27.0
Vinyl chloride	4.0	21.7
Water gas (variable)	6.0	6.0
Xylene (xylol)	1.0	6.0

Note: - Indicates not determined

Radiation from flares should be controlled to less than 34 000 kJ/(m^2-h) [3000 Btu/(ft^2-hr)] for equipment, 5000 kJ/(m^2-h) [440 Btu/(ft^2-hr)] for personnel on a continuous basis and 17 000 kJ/(m^2-h) [1500 Btu/(ft^2-hr)] for personnel on an intermittent basis. Provisions should be included for noise control in flare design.

Catalytic incinerators should be designed for a maximum particulate discharge to the atmosphere of 115 µg/Nm^3 (.05 gr/SCF). The gas stream entering the catalyst shall have a minimum temperature of 315°C (600°F) and a maximum inhibitor concentration (see Table 4-12) of 25 ppmv.

4.2.9 Incineration Systems Summary

Table 4-14 summarizes the qualitative features of each of the systems noted previously.

4.3 SPECIAL TOPICS

Combustion systems have been in use for several years burning wastes for energy and material recovery. Specific examples of these activities are:

- Firing spent pulping liquors in alkaline sulphate (kraft) and acid sulphite pulping to recover heat and chemicals in the manufacture of paper and wood cellulose products
- Combustion of waste oils in industrial boilers for recovery of heat and power generation
- The use of spent solvents and oils as fuel in the production of cement and lightweight ceramic aggregates

Table 4-14
Incineration System Summary

Incinerator Type	Waste Feed				Feed	Agitation	Hazardous	Biomedical	Ash Discharge		Supplemental Fuel			Excess Air	Wastewater	Particulate
	Solids	Liquids	Sludge	Gaseous	Preparation	of Waste	Waste	Waste	Wet	Dry	Liquid	Gaseous	Solid	Required	Discharge	Emissions
Multiple Chamber	Yes	Limited	Limited	Limited	Limited	Limited	Limited	Yes	Yes	Yes	Yes	Yes	Yes	High	None	High
Pyrolysis	Yes	Limited	Yes	Limited	High	None	Limited	No	Yes	No	Yes	Yes	Yes	None	Yes	High
Controlled Air	Yes	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Yes	Yes	Yes	Yes	No	Low	Ash pit	Moderate
Mass Burn	Yes	No	Limited	No	None	Limited	No	No	Yes	No	Yes	Yes	Yes	Moderate	Ash pit	Moderate
Semi-suspension	Yes	No	No	No	High	High	No	No	Yes	No	Yes	Yes	Yes	Moderate	Ash pit	Moderate
Rotary Kiln/Afterburner	Yes	Yes	Yes	Yes	Limited	High	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High	Yes	Moderate
Multiple Hearth	Limited	Limited	Yes	Limited	Limited	High	Limited	Limited	Yes	Yes	Yes	Yes	No	High	Yes	Moderate
Fluidized Bed	Limited	Yes	Yes	Limited	High	High	Yes	No	Yes	No	Yes	Limited	Yes	Low	Yes	Moderate
Liquid Injection	No	Yes	No	Limited	Limited	N/A	Yes	N/A	N/A	N/A	Yes	Yes	No	Low	None	Low
Direct Flame	No	No	No	Yes	None	N/A	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Low	None	Low
Catalytic	No	No	No	Yes	None	N/A	Yes	N/A	N/A	N/A	Yes	Yes	No	Low	None	Low

N/A: Not applicable

4.3.1 Spent Pulping Liquor Recovery Boilers

In alkaline (kraft) pulping of wood to produce paper and other cellulose products, a solution of sodium sulphide and sodium hydroxide is used to dissolve lignin and other soluble organic compounds from the cellulose fiber used to make paper. The spent "black liquor" from this alkaline digestion process contains sodium sulphate, sodium carbonate, lignin, and other organic materials dissolved from the wood. Oxidation of black liquor is extensively used to assist in odour control.

After concentration by multiple-effect evaporation, the black liquor is fired in a specially designed "recovery boiler." The ratio of primary to total air is carefully controlled to maintain a reducing (oxygen deficient) atmosphere in the furnace bed (to convert sulphate to sulphide) while maintaining an oxidizing atmosphere in the upper zone of the furnace. Excess air added above the furnace bed assures combustion of volatile organics and oxidation of gaseous sulphide compounds to sulphur dioxide. As the organic material is burned off at approximately 840°C to 850°C (1540°F to 1560°F) in the char-bed, the remaining inorganic sodium salts, principally sodium carbonate and sodium sulphide, form a smelt.

To recover chemicals for reuse in makeup of new cooking liquor, the smelt is dissolved and recausticized with lime to convert sodium carbonate to sodium hydroxide. Steam from the recovery boiler is used for evaporation of the spent black liquor and drying in the paper machines.

If oxidation above the furnace bed is not complete, principal air emissions include particulate resulting from sublimation of sodium salts and odours produced by reduced sulphur compounds including hydrogen sulphide, mercaptans, and other organic sulphides.

Corrective odour control measures require analysis of specific situations; no single solution found satisfactory at one location generally can be transferred without modification to another location. In general, conversion from a direct-contact evaporator to an indirect-contact evaporator and maintenance of excess oxygen in the recovery boiler reduces odour problems. Mills with direct-contact evaporators can operate at low emission rates of total reduced sulphur (TRS) if the flue gas is controlled to maintain 2 to 3% oxygen. Using a caustic scrubber in the flue gas emissions control system would also result in very low TRS emissions.

In acid sulphite pulping where chemicals are recovered, wood chips are "cooked" with a sodium, magnesium, or ammonium sulphite or bisulphite cooking liquor. The spent "red liquor" from this digestion process contains sulphate salts and dissolved organics that bind the cellulose fibers together in wood. The red liquor is concentrated by multi-effect or vapour recompression evaporation and normally burned in an oxidizing recovery boiler. In the combustion process sodium and magnesium form metal oxides and sulphur compounds are converted to sulphur dioxide. Where ammonium ion is used as the base salt, combustion converts ammonia to nitrogen gas and water.

The metal oxides are recovered as particulate from the flue gas and dissolved in water to produce sodium or magnesium hydroxide. Sulphur dioxide in the flue gas is absorbed with water to produce sulphurous acid. Combining the recovered metal (sodium or magnesium) hydroxide with sulphurous acid then produces new sodium or magnesium sulphite/bisulphite cooking acid. This completes the chemical recovery process. As with alkaline pulping, steam from the recovery boiler is used for spent liquor evaporation and paper drying.

Temperature within the boiler depends on the complex heat and mass transfer reactions that occur. Complete combustion of the organic solids is essential for heat output and chemical recovery. This means that the spent-liquor feed rate and residence time in the high-temperature zone of the furnace must be balanced.

Air emissions include unrecovered particulate metal oxides and sulphur dioxide. Venturi scrubbers utilizing absorbent liquors have out-performed packed towers in the removal of SO_2 from stack gases. Final SO_2 concentrations from the stack should be less than 250 mg/l.

4.3.2 Burning of Wastes in Industrial Boilers

Generally, liquid wastes, as opposed to solid or sludge wastes, have been fired in power boilers. Destruction of waste components in excess of 99% of their initial concentration occurs in industrial boilers when temperatures are maintained in excess of 980°C (1800°F) and a minimum residence time of 1.5 seconds for most nonhalogenated materials and 1200°C (2200°F) and 2-second residence time for halogenated waste. The boiler should have good mixing in the combustion chamber and a good control system.

When burning wastes in boilers, blending and operation plans should be developed to address:

- Additional gas cleaning requirements necessary to handle the ash content of waste fuels

- Control of hydrogen chloride or other acid gas resulting from the burning of waste fuels

- Increased maintenance of boilers and air-cleaning equipment resulting from the use of waste fuels

- Installation of ash discharge equipment at the bottom of the boiler to catch and discharge accumulated bottom ash

In general, criteria for waste firing in a boiler include the following:

Gross waste heating value	>18,000 kJ/kg, as fired
Ash content	<1.5%, as fired
Chloride content of the organic matter	>0.5%, as fired

Minimum operation temperature 870°C (1600°F)

4.3.3 Burning of Wastes in Cement Kilns

Cement kilns and light aggregate kilns operate at maximum temperatures between 1100°C and 1400°C (2010°F and 2550°F) with gas phase residence times of 40 to 120 seconds in the kiln. Particulate discharges are normally controlled by baghouses or electrostatic precipitators. Afterburners are normally not used. The controls for monitoring temperature, air flows, feed rates, and excess oxygen are typically in place as part of the cement kiln control process.

Use of these kilns for wastes should address:

- Additional burner for waste liquid
- Adequate mixing of the waste in the kiln for proper oxidation
- Any increased requirement to control particulate due to additional mixing requirement in the kiln
- Flow control of waste to the kiln
- Potential product (clinker) degradation from residual ash from the waste stream

Chloride emissions are not expected to be a concern. Hydrogen chloride reacts with the lime clinker feed to form calcium and magnesium salt, which would be retained in the cement solids and would be a comparatively insignificant component of these solids.

A major concern in waste firing is the location of the introduction of waste to the kiln. If waste is introduced at the low-temperature end of the kiln, the temperature is usually high enough to volatilize the higher combustibles within the waste stream. These volatiles may pass through the system uncombusted to the atmosphere and create emission problems. If introduced at the hot end of the kiln where cement clinker is discharged, there may be insufficient residence time for the noncombustibles of the waste to mix and blend with the clinker, and inferior product quality may result. Therefore, a separate burner is required for the waste combustion. The type of waste, its volatility, and the nature of the production process in question must be evaluated carefully to determine if a particular waste can be effectively fired and destroyed.

4.4 DEVELOPING TECHNOLOGIES

There are a number of other technologies that have been developed for the thermal destruction/treatment of hazardous wastes. Following are descriptions of a number of these alternative treatment systems.

4.4.1 Circulating Fluid Bed

In the circulating bed (Figure 4-22), combustible waste is introduced into the bed along with recirculated bed material from the hot cyclone. Both the fresh feed and the recirculating material are fed into the combustion chamber. A high air velocity (4 to 6 m/s) results in carryover of both bed material and the combustible waste, which rise through the reaction zone to the top of the combustion chamber and pass into a hot cyclone. The cyclone separates hot gas from solids, which are reinjected to the combustion chamber via the return seal. The hot flue gases pass to a gas cooler, then to a baghouse filter. Bed material could include alkali substances to capture and retain acid gases (HCl and SO_2).

Tests indicate that efficient combustion can be accomplished over a wide range of operating conditions, as follows:

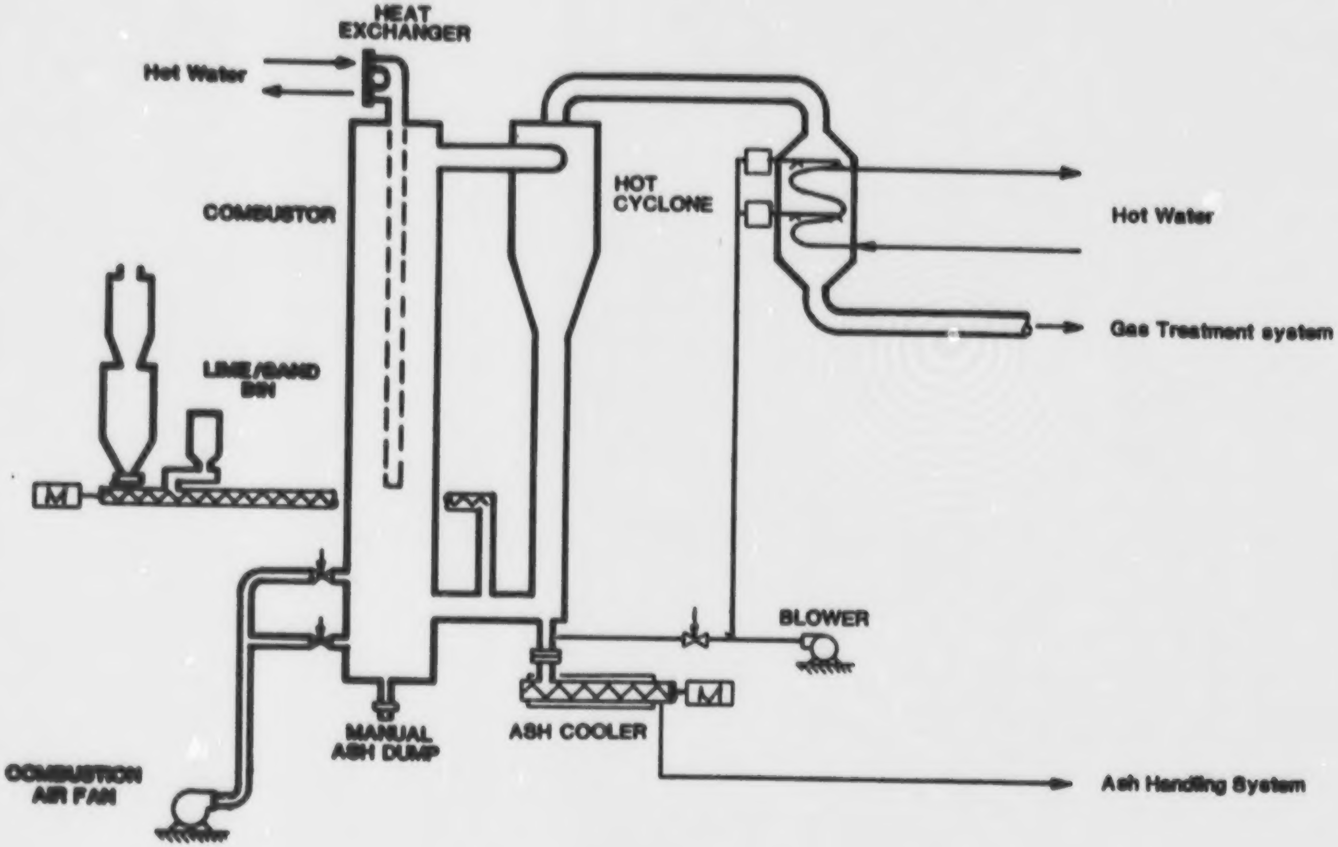

HEAT EXCHANGER
Hot Water
COMBUSTOR
LIME/SAND BIN
HOT CYCLONE
Hot Water
Gas Treatment system
BLOWER
MANUAL ASH DUMP
ASH COOLER
COMBUSTION AIR FAN
Ash Handling System

Figure 4-22
CIRCULATING FLUID BED

Temperature - 780°C to 870°C (1436°F to 1598°F)

Excess Air - 15% to 100%

Air Velocity - 0.9 to 6 m/s (3 to 20 ft/s)

Form of Waste Feed - Solid, slurry, liquid, sludge

Waste Composition - 0% to over 90% ash
0% to over 90% water
0% to 50% chlorine
0% to 30% fluorine, sulphur, or sodium

Combinations of these operating conditions have been found to yield over 99.99% waste destruction. The high degree of mixing action in the combustor allows feeds of wide variation in viscosity to be incinerated effectively.

4.4.2 Rotary Reactor

The rotary reactor consists of a hollow, three-compartment cylinder that rotates from 10-30 revolutions per minute. The rotary reactor acts as a fluidized bed with a hot inert medium (e.g., sand) with solid or semi-solid wastes mechanically lifted on internal radial fins and cascaded through the combustion gases in the combustion zone. The solid cascading action provides effective mass transfer and high rates of heat transfer. This results in destruction efficiencies of greater than 99.99% at 870°C (1598°F).

The major features of the rotary reactor are:

- Ability to incinerate wastes with a heat content as low as 4600 kJ/kg (2,000 Btu/lb) as fired without auxiliary fuel
- The use of coal as an auxiliary fuel for wastes with heating values less than approximately 4600 kJ/kg (2,000 Btu/lb)
- Neutralization of acidic combustion gases by the addition of lime to the combustion chamber. This reduces the gas scrubbing requirements and also simplifies the materials of construction.

4.4.3 Molten Salt Incineration

The molten salt process (Figure 4-23) has been developed to dispose of a wide variety of wastes: solids, liquids, and sludges. It is an oxidation and recombinant process whereby wastes are oxidized and/or chemically altered to innocuous substances.

Soluble alkali salts are used as the bed material. A single salt or a mixture of salts can be used. The more common salts in use are sodium chloride (NaCl), sodium sulphate (Na_2SO_4), sodium phosphate (Na_3PO_4), sodium carbonate (Na_2CO_3), and corresponding calcium salts.

The salt bed is heated to fluidization, its temperature a function of the salt material utilized. Waste is prepared before feeding (if solid wastes, by shredding) and is fed directly into the molten salt bed if liquid or sludge. Typical temperatures of the bed are in the range of 700°C to 850°C (1290°F to 1560°F).

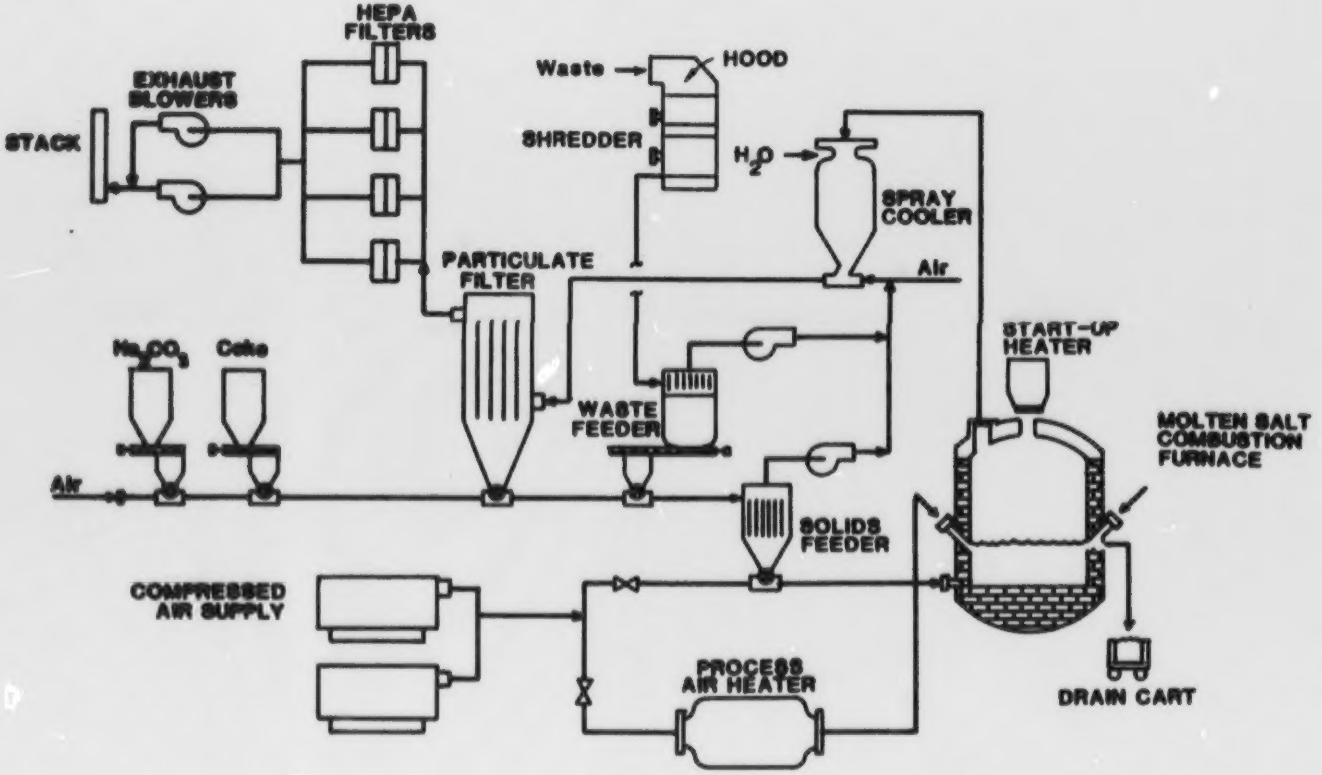

HEPA FILTERS
EXHAUST BLOWERS
STACK
Waste
HOOD
SHREDDER
H_2O
SPRAY COOLER
Air
PARTICULATE FILTER
Na_2CO_3
Coke
Air
WASTE FEEDER
START-UP HEATER
MOLTEN SALT COMBUSTION FURNACE
SOLIDS FEEDER
COMPRESSED AIR SUPPLY
PROCESS AIR HEATER
DRAIN CART

Figure 4-23
MOLTEN SALT INCINERATOR

Waste components dissolve within the melt, producing an off-gas. The off-gas will contain carbon dioxide and moisture (steam), and oxygen and nitrogen from the air supply. It will also contain particulate matter, salt, and other components generated within the melt. After particulate removal, the gas is discharged to the atmosphere.

The volume of the melt increases as waste is added to the system and it must be tapped periodically. Many compounds can be separated from the salt and the salt can be recycled to the incinerator for reuse.

Off-gas is exhausted through a quench or spray cooler where its temperature is reduced below 150°C (302°F). At this temperature the gas can pass through electrostatic or fabric filters for particulate removal prior to discharge through induced draft blowers feeding an exhaust stack. High efficiency particulate air filters (HEPA filters) may or may not be necessary, depending on the particulate loading and size distribution.

Liquid and sludge waste can be taken directly to the incinerator and charged beneath the melt surface. Solid waste is shredded to uniform size and is then transferred to a waste feeder. Shredded solid waste, residue from the particulate filter, fresh salt, and coke is conveyed through a single pipeline to a solids feeder which, in turn, feeds the furnace.

Combustion products from a typical molten salt process are as follows:

Salt: Sodium Carbonate
Oxidizing Agent: Air

Element In Feed	Combustion Product
Carbon	Carbon Dioxide
Hydrogen	Steam
Chlorine, Fluorine	Sodium Chloride, Fluoride
Phosphorus	Sodium Phosphate
Arsenic	Sodium Arsenate
Sulphur Silicon	Sodium Sulphate
Silicon (Glass)	Sodium Silicate
Iron (Stainless Steel)	Iron Oxide
Silver (Photo Film)	Silver Metal

4.4.4 Flash Drying

Flash drying is a system used for disposal of various sludge wastes. Sludge waste is dried and can then be burned or disposed of by another method or within the flash drying system. Its principal elements (note Figure 4-24) are a hot gas heater, sludge mixer, cage mill, cyclone collector, vapour fan, and dry product conveyor.

Wet sludge is blended with a small quantity of dried sludge in the mixer to improve its transportability. This mixed sludge is fed to a windbox on the cage mill where hot gas, from 540°C to 760°C (1004°F to 1400°F) (depending upon the nature of the sludge), contacts the sludge. Moisture begins to evaporate into steam. The mixture of sludge, hot gas, and steam is ground together in the cage mill. The sludge is pneumatically conveyed to a cyclone where separation of dry sludge from gas and moisture vapour occurs by flashing at approximately 150°C (302°F).

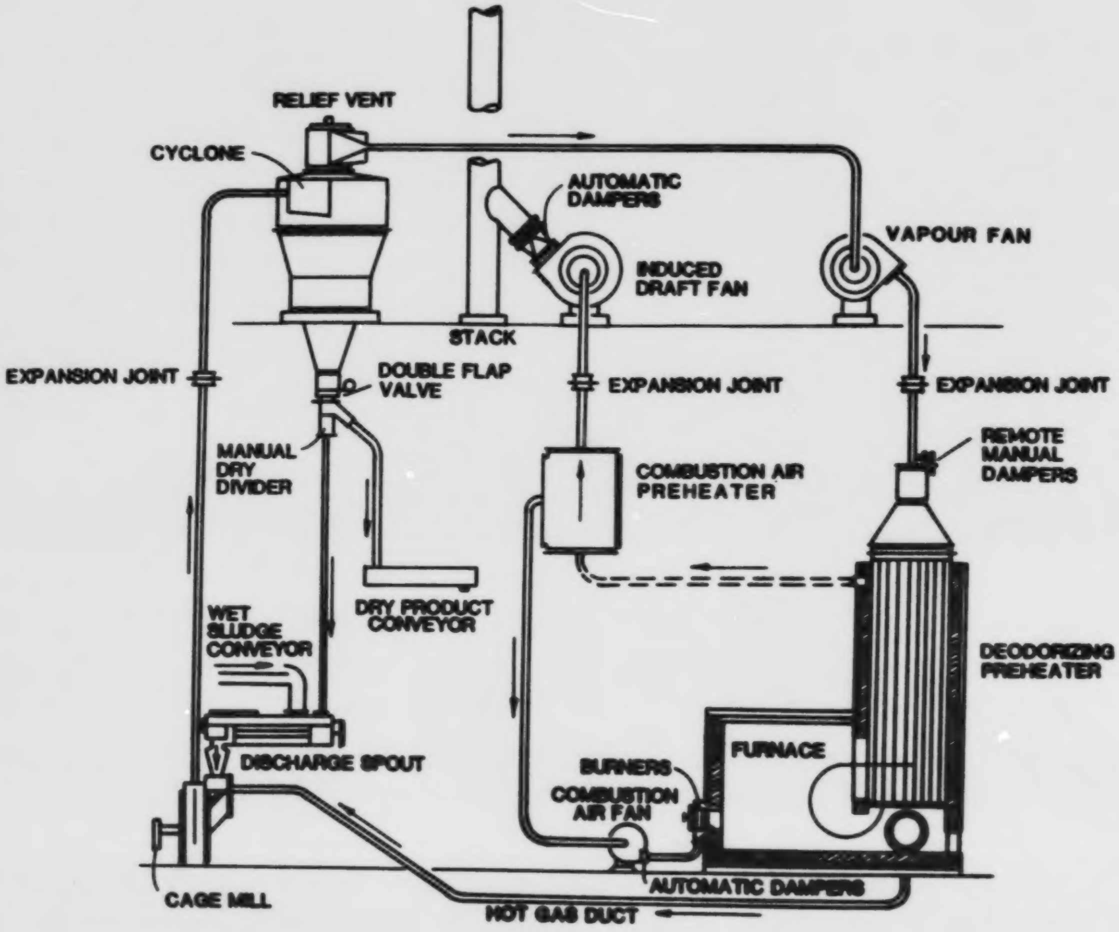

RELIEF VENT
CYCLONE
AUTOMATIC DAMPERS
VAPOUR FAN
INDUCED DRAFT FAN
STACK
EXPANSION JOINT
DOUBLE FLAP VALVE
EXPANSION JOINT
EXPANSION JOINT
MANUAL DRY DIVIDER
REMOTE MANUAL DAMPERS
COMBUSTION AIR PREHEATER
DRY PRODUCT CONVEYOR
WET SLUDGE CONVEYOR
DEODORIZING PREHEATER
FURNACE
BURNERS
DISCHARGE SPOUT
COMBUSTION AIR FAN
CAGE MILL
AUTOMATIC DAMPERS
HOT GAS DUCT

Figure 4-24
FLASH DRYER SYSTEM

A dry sludge (containing 4 to 8% moisture) is discharged by the dry product conveyor. This material can be burned to produce the hot gas required for initiation of the process. The dry product can be incinerated to produce the steam required by the process or it can be taken away for alternate disposal or use. The furnace utilizes conventional fuel for generating hot gas; the dry sludge is removed from the process as a dry material.

The spent gases from the cyclone must be incinerated prior to discharge to the atmosphere. In this process a vapour fan blows these gases from the cyclone to a vertical heat exchanger (recuperator) within the furnace. The spent gas picks up heat from the recuperator and is heated further within the furnace to 760°C (1400°F). At this temperature, with a residence time in excess of 0.5 seconds, the odour components will destruct. The hot gas will pass over tubes in the recuperator, losing some of its heat to the incoming gas. The gas continues to another heat exchanger, a preheater, which heats combustion air prior to its injection into the furnace adjacent to the supplemental fuel burner. The spent gas will exit the preheater and will discharge from the stack at approximately 260°C (500°F).

4.4.5 The Carver-Greenfield Process

The Carver-Greenfield process (Figure 4-25) is a method of drying moisture-laden liquid or sludge through heating and evaporation.

After waste feed is passed through a grinder to give it a uniform consistency, it is pumped to a fluidizing tank where an oil is added and mixed with the sludge. The feed/oil mixture passes through a series of evaporators where the moisture is evaporated leaving the solids sus-

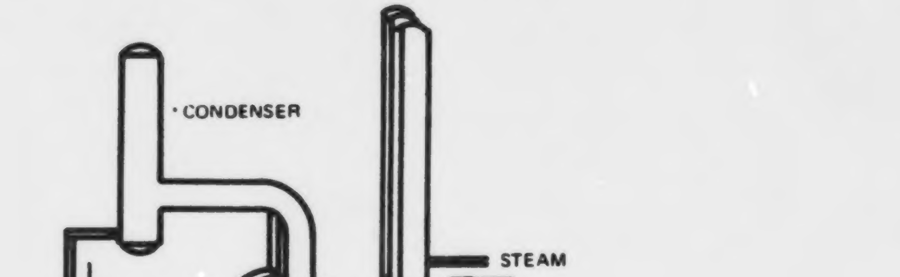

CONDENSER
STEAM
CLEAR WATER
SINGLE
OR
MULTI
EFFECT
EVAPOR-
ATOR
RAW
MATERIAL
IN
CENTRIFUGE
PRODUCT OUT
CONVEYOR
RECYCLE
OIL
TANK
FLUIDIZING
TANK

Figure 4-25
CARVER-GREENFIELD PROCESS

pended in the carrier oil. Four stages of evaporation are often used; however, because the number of stages required is a function of feed properties, as few as two stages may be sufficient for some materials.

The feed is pumped through a heat exchanger prior to each stage of evaporation and ultimately is discharged to a centrifuge. The centrifuged solids will normally contain less than 1% of the original oil added to the feed and less than 2% by weight of moisture. The dry solids can be burned to provide steam for the evaporators or, as with flash dryers, they can be disposed of outside the system.

The balance of the equipment used in this process captures and recovers the carrier oil to allow its reuse.

Off-gases, including spent steam, from this system are normally burned in the steam boiler as combustion air. The atmospheric discharge from this system is the stack from the steam boiler. The only other discharge is the dried product.

4.4.6 High Temperature Fluid Wall Reactor

The High Temperature Fluid Wall (HTFW) reactor (Figure 4-26) consists of a tubular core of porous graphite which is capable of emitting sufficient radiant energy to destroy organic contaminants. The core is completely jacketed and insulated in a gas-tight pressure vessel. Electrodes located in the annular space between the jacket and the core provide the energy required to heat the core to radiant temperatures.

This system has been developed for the destruction of soil-bound organic contaminants. Raw materials are ground to a relatively fine mesh and are dried to a moisture

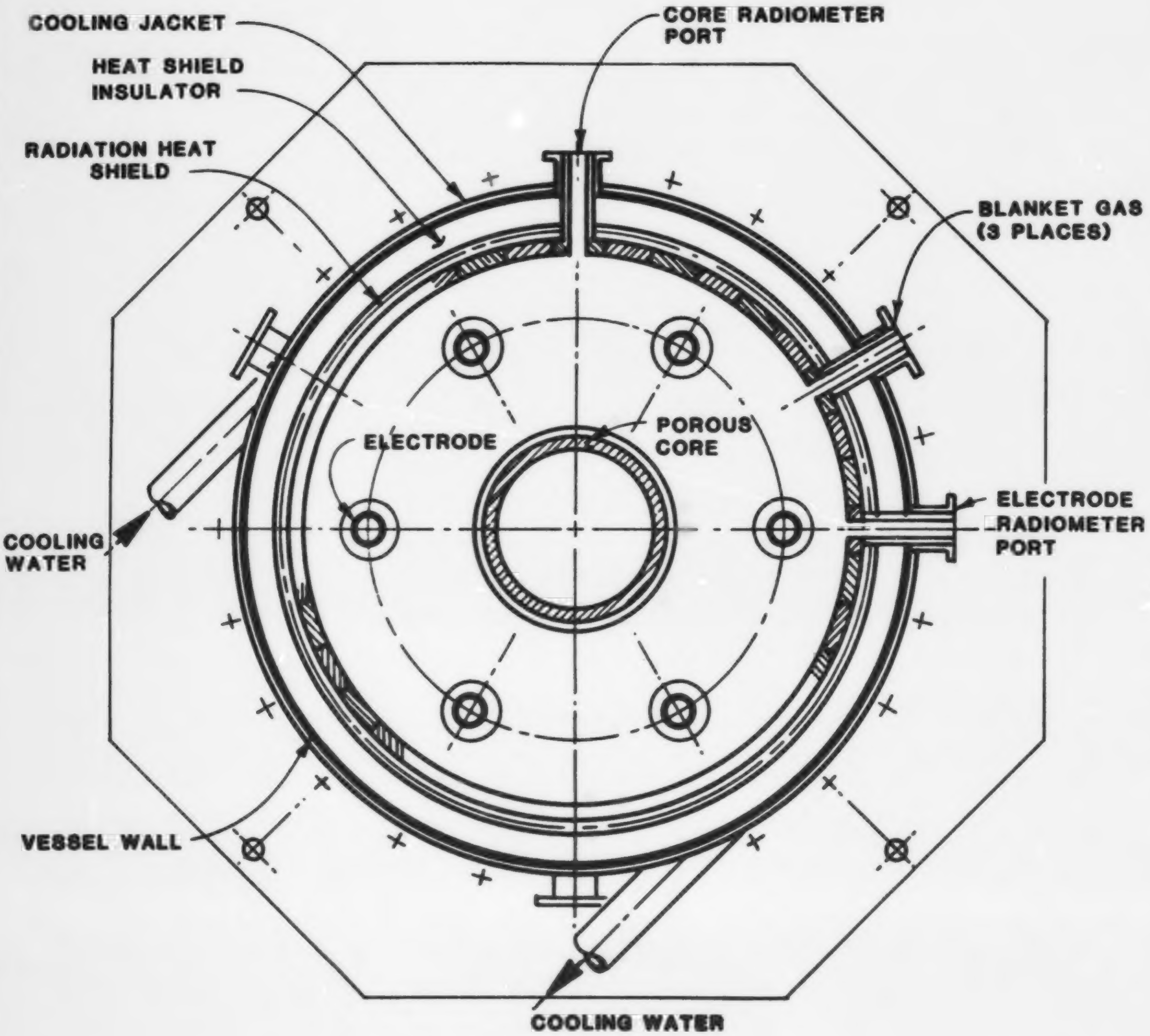

COOLING JACKET
HEAT SHIELD INSULATOR
RADIATION HEAT SHIELD
CORE RADIOMETER PORT
BLANKET GAS (3 PLACES)
ELECTRODE
POROUS CORE
ELECTRODE RADIOMETER PORT
COOLING WATER
VESSEL WALL
COOLING WATER

Figure 4-26
HIGH TEMPERATURE FLUID WALL REACTOR

content less than 8%. The material is dropped by gravity into the reactor feed throat.

The core is heated by the external electrodes and its inner surface re-radiates the energy into the tubular space where the materials are introduced. Temperatures in the range of 2200°C to 2800°C (3990°F to 5070°F) are produced, causing the organic contaminants to be volatilized. The advantages of this method of energy transfer are that the organic contaminants are almost instantaneously heated and the chemical reactions are greatly accelerated without heating the entire process stream to the reaction temperature.

The core and electrodes are insulated within the reactor jacket by graphite materials. The reactor exhausts to a water-jacketed heat exchanger. After cooling, the reaction products enter a collection tank. Airborne particulate is captured with a cyclone and baghouse.

4.4.7 Wet Air Oxidation

Wet air oxidation is a process whereby a sludge will release bound water upon application of heat. Sludges that are colloidal gels, such as organic sludges, are composed of minute particles bound by sheaths that contain water as well as sludge solids. Upon application of heat, the sheath will dissolve, releasing the bound water within the sludge particle. Upon release of bound water, the sludge solids can be dewatered or further processed.

Thermal conditioning is a low pressure wet air oxidation process where the end product, thermal-conditioned sludge, is readily dewaterable. High pressure wet air oxidation produces a sludge that is not only dewaterable but that has been oxidized.

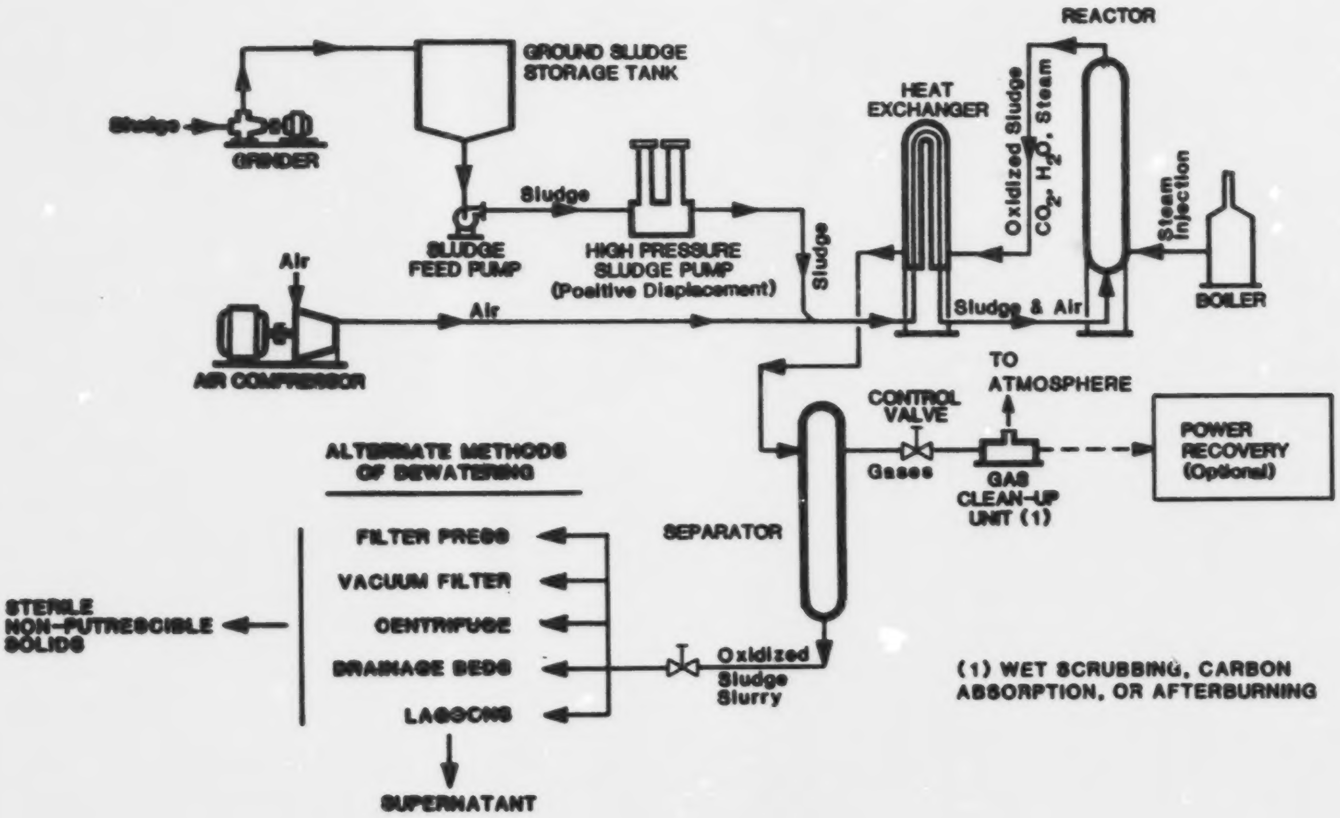
Referring to Figure 4-27, raw sludge is first ground to uniform consistency. For thermal conditioning the reactor pressure will be from 1.2 to 1.4 MPa and for high pressure oxidation the reactor pressure can be as high as 8.2 to 16 MPa.

Compressed air is injected into the sludge feed. Air provides turbulence within the sludge stream, increasing heat transfer efficiency through the heat exchanger(s). It is also required for oxidation of malodourous, gaseous compounds released with the release of bound water. High pressure wet air oxidation, however, requires additional air for oxidation of the sludge solids. Depending on the amount of air injected into the sludge and system pressure, the conditioned sludge can be partially oxidized or can be oxidized to a sterile ash.

Steam is injected within the reactor to provide the required reactor pressure and residence time. Temperatures range from 150°C to 340°C (302°F to 644°F), and normal residence time within the reactor is from 10 to 30 minutes.

The hot sludge exiting the reactor passes through one or a series of heat exchangers where most of the available heat is transferred to the entering raw sludge to reduce the total system heating requirements. Raw sludge is pumped through the heat exchanger tubes and the hot conditioned sludge is on the shell side of the heat exchanger.

From the heat exchanger, the conditioned sludge goes to a separator, or storage tank, where a quiescent period is provided. Gases are released and these gases are highly odourous. They are normally incinerated before discharge to the atmosphere.


REACTOR
GROUND SLUDGE STORAGE TANK
HEAT EXCHANGER
Oxidized Sludge
CO_2, H_2O, Steam
Sludge
GRINDER
Sludge
Steam Injection
SLUDGE FEED PUMP
HIGH PRESSURE SLUDGE PUMP (Positive Displacement)
Sludge
Air
Air
Sludge & Air
BOILER
AIR COMPRESSOR
TO ATMOSPHERE
CONTROL VALVE
POWER RECOVERY (Optional)
ALTERNATE METHODS OF DEWATERING
Gases
GAS CLEAN-UP UNIT (1)
SEPARATOR
FILTER PRESS
VACUUM FILTER
STERILE NON-PUTRESCIBLE SOLIDS
CENTRIFUGE
DRAINAGE BEDS
Oxidized Sludge Slurry
LAGOONS
SUPERNATANT

(1) WET SCRUBBING, CARBON ABSORPTION, OR AFTERBURNING

Figure 4-27
WET AIR OXIDATION

4.4.8 Supercritical Fluid Oxidation

This is an experimental system and has not been demonstrated outside the laboratory.

Supercritical fluid oxidation is basically a high temperature, high pressure wet oxidation process, as shown in Figure 4-28. Above the critical temperature, 399°C (750°F), and pressure, 22.1 MPa of water, organic materials and gases are completely miscible with water. Organics, air, and water are brought together in a mixture of 25 MPa and temperatures in excess of 400°C (752°F). Organic oxidation occurs spontaneously at these conditions. The heat of combustion is released within the fluid, and it results in a rise in temperature to 590°C to 650°C (1094°F to 1202°F). Under these conditions, organics are rapidly oxidized with efficiencies that have been measured in excess of 99.999%.

The waste, as either an aqueous solution or a slurry, is pressurized and delivered to the oxidizer inlet. It is heated to supercritical conditions by direct mixing with recycled reactor effluent. Oxygen is supplied in the form of compressed air, which is used as the motive fluid in an eductor to provide recycle of a portion of the reactor effluent. This inlet mixture is then a homogeneous phase of air, organics, and supercritical water.

The heat released by combustion of readily oxidized components is sufficient to raise the fluid phase to temperatures at which all organics are oxidized rapidly. The discharge from the oxidizer is fed to a cyclone. The solubility of inorganics in supercritical water is extremely low at the reactor effluent temperatures. Inorganic salts that are originally present in the feed or

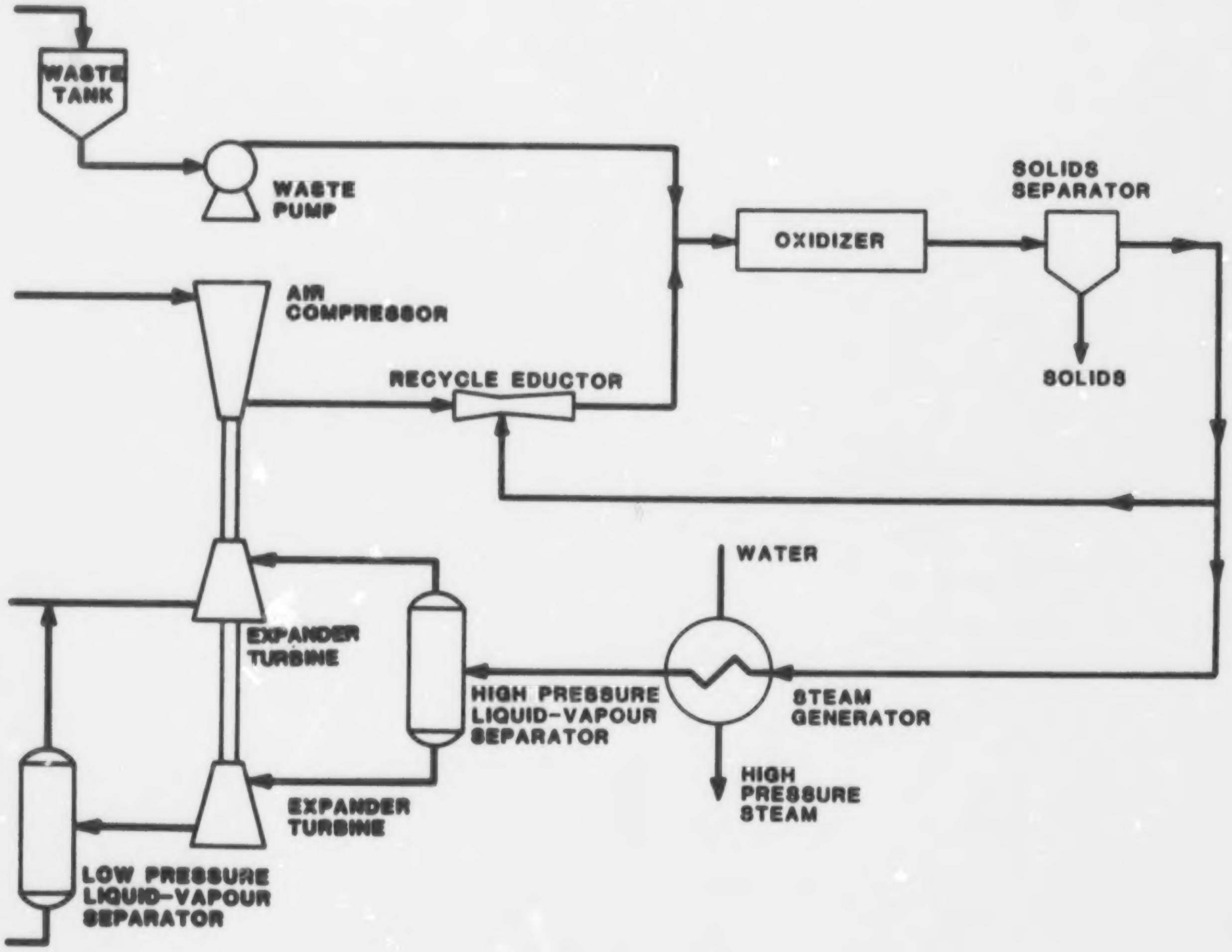

WASTE TANK
WASTE PUMP
AIR COMPRESSOR
RECYCLE EDUCTOR
OXIDIZER
SOLIDS SEPARATOR
SOLIDS
WATER
EXPANDER TURBINE
HIGH PRESSURE LIQUID-VAPOUR SEPARATOR
STEAM GENERATOR
HIGH PRESSURE STEAM
EXPANDER TURBINE
LOW PRESSURE LIQUID-VAPOUR SEPARATOR

Figure 4-28
SUPERCRITICAL FLUID OXIDATION

which form in the combustion reactions precipitate out of the fluid phase in the oxidizer and are separated.

The fluid discharge of the solid separator consists of superheated, supercritical water, N_2, and CO_2. A portion of this stream is recycled through the eductor to provide supercritical conditions at the oxidizer inlet. The remainder of the effluent is available as a high-temperature, high-pressure fluid for energy recovery. This stream is cooled to a supercritical temperature in a heat exchanger that serves to generate low-pressure and high-pressure steam. Now at a substantial temperature, the mixture has formed two phases and enters a high-pressure, liquid-vapour separator. Almost all of the N_2 and some of the CO_2 leaves with the gas stream. The liquid consists of water with an appreciable amount of dissolved CO_2.

4.4.9 Plasma Systems

Plasma systems use the extremely high temperatures developed within the plasma stream to destroy hazardous organic wastes.

An electric arc is generated and is stabilized by a field coil through which an electric current is passed. As air passes the arc (Figure 4-29), electrical energy is converted to thermal energy by absorption by the nitrogen and oxygen molecules. They are activated into ionized atomic states, losing electrons in the process. Ultraviolet radiation is emitted when the molecules or atoms relax from their highly activated states to lower energy levels.

The resulting gas is in the plasma state and consists of charged and neutral particles with an overall charge near zero and with isolated temperatures over 25 000°C

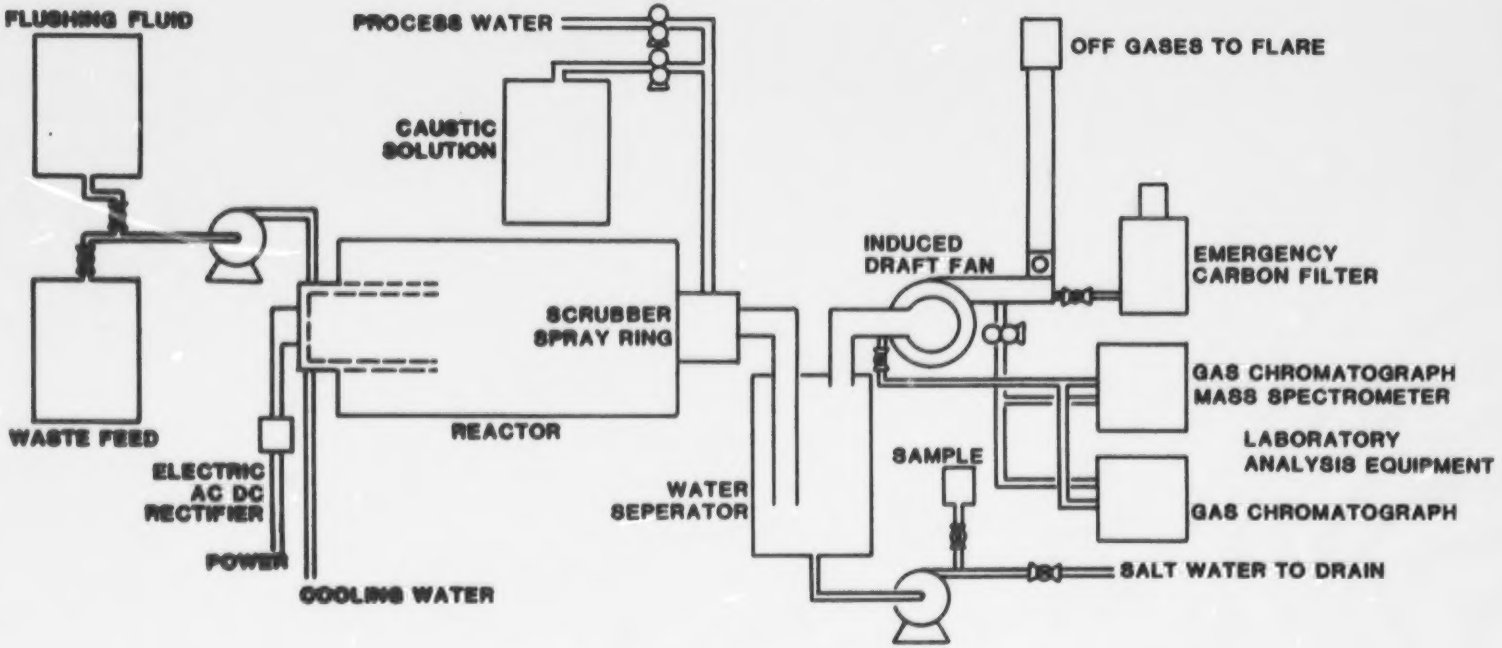

FLUSHING FLUID
WASTE FEED
PROCESS WATER
CAUSTIC SOLUTION
SCRUBBER SPRAY RING
REACTOR
ELECTRIC AC DC RECTIFIER
POWER
COOLING WATER
OFF GASES TO FLARE
INDUCED DRAFT FAN
EMERGENCY CARBON FILTER
GAS CHROMATOGRAPH MASS SPECTROMETER
LABORATORY ANALYSIS EQUIPMENT
GAS CHROMATOGRAPH
SAMPLE
WATER SEPERATOR
SALT WATER TO DRAIN

Figure 4-29
PLASMA ARC SYSTEM

(45,000°F). As the activated components of the plasma decay, their energy is transferred to the waste materials exposed to the plasma; the wastes are ultimately decayed and destroyed.

The feed is a liquid stream. Residence time within the reactor is approximately one second.

Destruction efficiencies in excess of six nines (99.9999%) have been demonstrated on PCB-contaminated aqueous streams.

A pilot plant was built to demonstrate process operation. It was sized to destroy approximately 225 kg/h (496 lb/hr) of liquids, and fits along with the necessary auxiliary equipment on a semitrailer. This unit is operational.

The testing of this technology has been the subject of continuing support from United States regulatory authorities. The fabrication of a mobile unit capable of treating from 3.5 to 9.5 litres (1 to 2.5 gal) per minute of waste was completed in the spring of 1984 and is used in a demonstration of this technology.

4.4.10 Radioactive Waste Treatment

The vast majority of radioactive waste generated is low level radioactive waste (LLW), which is neither spent fuel nor high-level waste and contains less than 10 nanocuries of transuranics per gram of material. Transuranic material (TRU) refers to uranium or materials, natural or man-made, with atomic weight equal to or greater than that of uranium.

Incineration reduces the volume of waste to be disposed of; it has no effect on radiation itself. Handling, storage, and feeding of material must be carefully controlled. Tight containers and negative ventilation systems exhausting through high efficiency particulate air filters (HEPA) are necessary prior to feeding and incineration.

Incinerator feeding must be designed to preclude the possibility of the escape of hot gases (which may contain LLW) from the incinerator from back-charging into the feeding room when the incinerator charging door is open. This normally requires that the charging system be provided with a series of air locks and multiple feeding chambers to isolate the incinerator gas under all conditions of operation.

Emergency exhaust systems, such as explosion doors used in conventional incineration systems, cannot normally be used when burning LLW. The opening of a door or stack prior to the exhaust gas-cleaning train would discharge LLW to the surrounding air. This requirement may preclude incineration of certain wastes that may cause explosions or the use of supplemental fuel such as natural gas, which is more volatile than other fuels.

The furnace itself in many installations is pyrolytic to minimize gas flow. Off-gas passes first through a permanent type hot gas filter. A HEPA filter will capture residual particulate and after it is spent, the filter is charged to the furnace.

Chapter 5
ENERGY RECOVERY

5.1 INTRODUCTION

Energy recovered from incineration is addressed in this chapter. Heat generated in the incineration process can be used to heat combustion air, reheat the scrubber discharge to eliminate its plume, or generate steam or hot water for various process requirements.

The cost of producing equivalent energy from fossil fuel provides an economic incentive to reclaim the waste heat from incinerators. Additionally, installation of a waste heat recovery system can enable downstream systems, such as scrubbers and other air pollution control units, to be downsized due to the reduced airflow at lower temperatures, thereby decreasing capital and operating costs.

In practice, not all forms of heat recovery systems will be appropriate for any incinerator. Energy recovery by producing hot water or steam for export usually requires relatively constant operation of the incinerator system since the rate of usage is generally continuous. While energy recovery for external use may be practical for larger municipal refuse incineration systems, it is less attractive for mobile or industrial waste incinerators, which normally operate intermittently for several hours per day or week. However, in both continuously and intermittently operated incinerators, the potential for some internal energy recovery from the incinerator flue gas often exists (e.g. heating incinerator combustion air or reheating the scrubber discharge gases).

5.2 ENERGY RECOVERY POTENTIAL

5.2.1 Heat Recovery Media

The potential media for heat recovery systems are air, water, and steam. Because air has relatively low heat capacity, its use in heat recovery systems is usually limited to combustion air heating, scrubber gas reheating, and seasonal space heating. Additionally, because of the large volumes of hot air involved and the low heat-transfer coefficient for air-to-air heat exchangers, large-diameter ductwork and large plant areas are required.

Water can be used in heat recovery systems; however, hot water uses in plants are normally limited to seasonal space heating and feedwater heating in limited quantities.

Steam is used for incinerator heat recovery far more frequently than hot water or hot air. Steam is more versatile in its application and contains significantly more energy for the same mass. Steam can be used for process requirements for year-round equipment loads; it can be used to generate electricity; and it can be converted easily to hot water or used for air heating when these needs arise.

The following sections present further guidance on the evaluation of steam-based energy recovery systems.

5.2.2 Available Heat

The available heat in the incinerator flue gas for steam production is equal to its heat at the boiler inlet less its heat at the boiler outlet.

For any heat exchanger there is an approach temperature, t_x, which is the difference between the temperatures of the heated medium (t) and the exiting flue gas (t_o).

Thus, $t_x = t_o - t$

The more efficient the heat exchanger, the lower the approach temperature.

In practice, the approach temperature of a waste heat boiler is in the order of 38°C (100°F) for very efficient and 65°C (150°F) for standard, economical construction.

Available heat from a flue gas stream (see Figure 5-1) is calculated as:

$$Q = W(h \text{ @ } t_i - h \text{ @ } t_o)$$

Where:

Q = available heat, kJ/kg
W = flue gas mass, kg/h
h = enthalpy of flue gas, kJ/kg
t_i = temperature of flue gas entering the boiler, °C
t_o = temperature of flue gas exiting the boiler, °C

The flue gas will have a dry and a wet component. Considering the dry gas component to have the properties of air, the above equation becomes:

$$Q = W_{dg}\ (h_{ai} - h_{ao}) + W_m\ (h_{mi}-h_{mo})$$

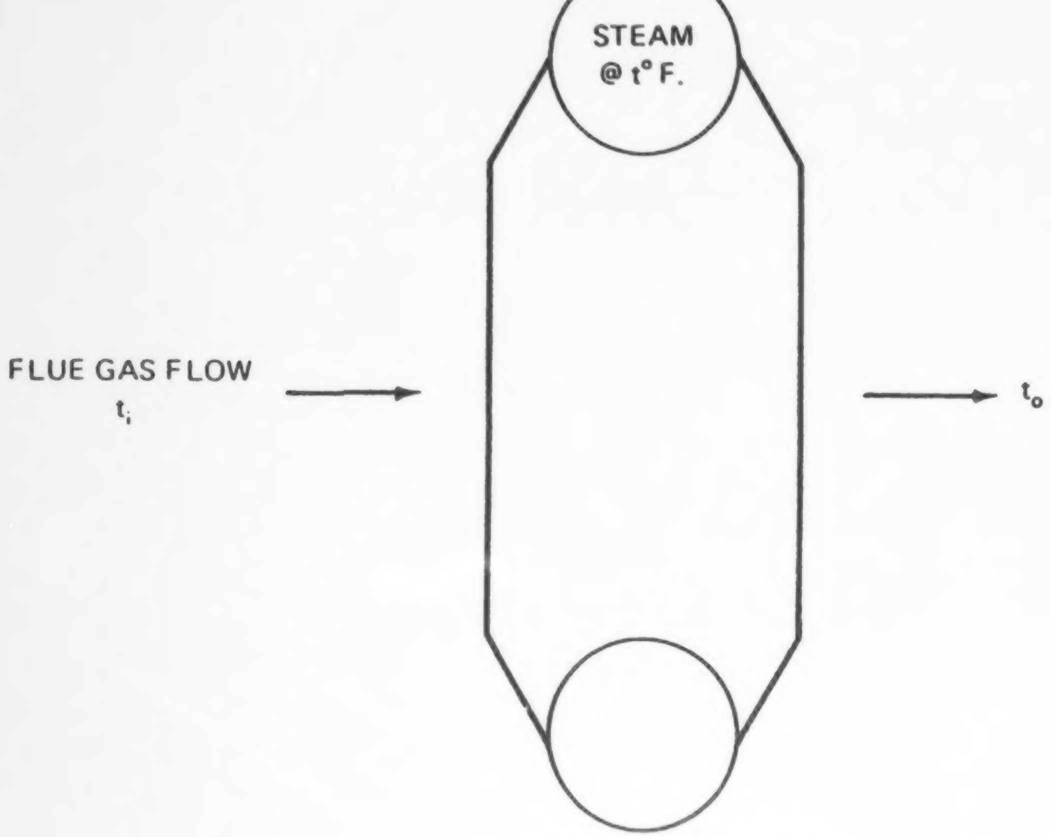

STEAM
@ t° F.
FLUE GAS FLOW
t_i
t_o

Figure 5-1
WASTE HEAT BOILER

Where:

W_{dg} = flue gas dry component, kg/h
W_m = flue gas wet component, kg/h
h_a = enthalpy of dry gas, kJ/kg
h_m = enthalpy of moisture, kJ/kg

Subscripts i and o correspond, respectively, to flue gas at the inlet and outlet of the heat exchanger (waste heat boiler).

5.3 STEAM GENERATION

5.3.1 Steam Generation Systems

Figure 5-2 shows a typical flow diagram for a steam-producing waste heat boiler. Waste heat from incinerator flue gas is absorbed in the boiler to produce steam. The produced steam is used in various plant processes, and the condensate is returned to the boiler via a deaeration system that strips dissolved oxygen and carbon dioxide from the feedwater to control corrosion in the boiler.

Periodic blowdown of the boiler water is required to maintain dissolved and suspended solids levels at an acceptable limit. Blowdown quantity is a function of boiler water chemistry and the temperature and pressure of the steam produced. Normally, boiler blowdown ranges from 1 to 5% of the steam generation rate.

Makeup water is required to replace blowdown and any steam losses in the system. The quality of the makeup water is determined by both the blowdown rate and particular boiler characteristics (i.e., pressure, heat transfer rate, etc.). In general, as boiler pressures increase, feed-

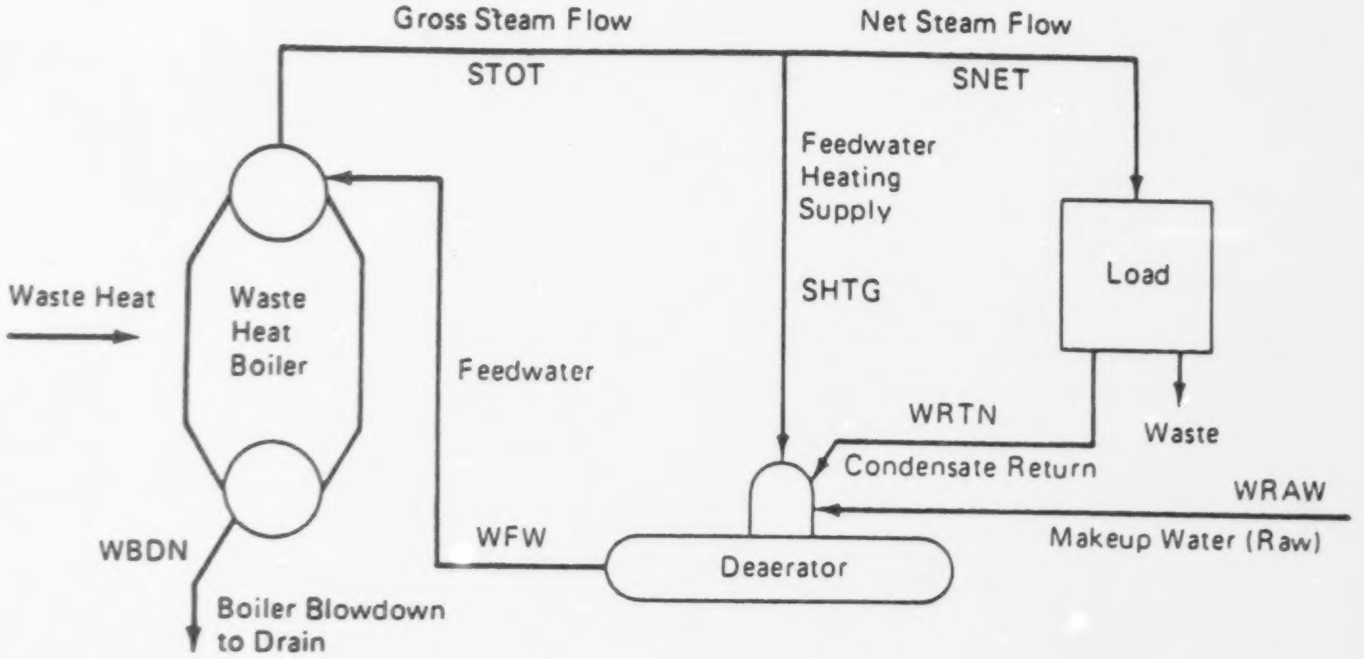

Gross Steam Flow
STOT
Net Steam Flow
SNET
Feedwater
Heating
Supply
SHTG
Load
Waste
Waste Heat
Waste
Heat
Boiler
Feedwater
WRTN
Condensate Return
WRAW
Makeup Water (Raw)
WFW
Deaerator
WBDN
Boiler Blowdown
to Drain

Figure 5-2

WASTE HEAT BOILER STEAM FLOW

water quality requirements become more stringent. Table 5-1 summarizes the ASME water quality guidelines for boilers fired with primary fuels. It is not uncommon for waste heat boilers to suffer from insufficient water-side circulation, areas of unavoidable deposit accumulation, and localized abnormally high heat fluxes. Consequently, it is recommended that a conservative approach be adopted and that demineralized makeup water meeting the specifications for boilers above 6.89 MPa (1000 psig) be provided for waste heat recovery units.

To meet these feedwater quality criteria, makeup water treatment requirements can be extensive; they typically comprise coagulation/precipitation/sedimentation processes, filtration, and ion exchange demineralization. These treatment processes generate waste sludges, dirty backwash water, and regeneration wastes, the disposition of which needs to be considered in the design of the overall waste management plan for an incineration facility.

Similarly, provision must be made for reuse or disposal of boiler blowdown. This waste stream contains the concentrated salts present in the makeup water as well as the chemicals used for internal boiler water treatment or chemical reaction products. Typical chemicals used for internal scaling and corrosion control include phosphates, organic sludge conditioners, chelating agents (EDTA), sodium sulphite, hydrazine, and amines.

5.3.2 Steam Generation Rate

Calculation of steam generation rate includes material (flow) and heat balances around the system. A typical waste heat boiler flow system is shown in Figure 5-2. Using the air and moisture enthalpy tables and the steam tables, calculations can be performed for obtaining steam,

Table 5-1
. Suggested Water Quality Limits

Boiler Type: Industrial watertube, high duty, primary fuel fired, drum type
Makeup Water Percentage: Up to 100% of feedwater
Conditions: Includes superheater, turbine drives, or process restriction on steam purity
Saturated Steam Purity Target (9)

Drum Operating Pressure (1) MPa (psig)	0-2.07 (0-300)	2.08-3.10 (301-450)	3.11-4.14 (451-600)	4.15-5.17 (601-750)	5.18-6.21 (751-900)	6.22-6.89 (901-1000)	6.90-10.34 (1001-1500)	10.3513.79 (1501-2000)
Feedwater (7)								
Dissolved oxygen (mg/l O_2) measured before oxygen scavenger addition (8)	<0.04	<0.04	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Total iron (mg/l Fe)	≤0.100	≤0.050	≤0.030	≤0.025	≤0.020	≤0.020	≤0.010	≤0.010
Total copper (mg/l Cu)	≤0.050	≤0.025	≤0.020	≤0.020	≤0.015	≤0.015	≤0.010	≤0.010
Total hardness (mg/l $CaCO_3$)	≤0.300	≤0.300	≤0.200	≤0.200	≤0.100	≤0.050	- Not Detectable -	
pH range @ 25°C	7.5-10.0	7.5-10.0	7.5-10.0	7.5-10.0	7.5-10.0	8.5-9.5	9.0-9.6	9.0-9.6
Chemicals for preboiler system protection						Use only volatile alkaline materials		
Nonvolatile TOC (mg/l C) (6)	<1	<1	<0.5	<0.5	<0.5	----- As low as possible, 0.2 -----		
Oily matter (mg/l)	<1	<1	<0.5	<0.5	<0.5	----- As low as possible, 0.2 -----		
Boiler Water								
Silica (mg/l SiO_2)	≤150	≤90	≤40	≤30	≤20	≤8	≤2	≤1
Total alkalinity (mg/l $CaCO_3$)	<350 (3)	<300 (3)	<250 (3)	<200 (3)	<150 (3)	<100 (3)	- Not Specified (4)-	
Free hydroxide alkalinity (mg/l $CaCO_3$)	------------------------------ Not Specified ------------------------------						-Not Detectable (4)-	
Sepcific conductance (µS/cm) (µmho/cm) @ 25°C without neutralization	<3500 (5)	<3000 (5)	<2500 (5)	<2000 (5)	<1500 (5)	<1000 (5)	<150	<100

NOTES FOR TABLE 5-1

1. With local heat fluxes >473.2 kW/m^2 (>150,000 Btu/hr/ft^2), use values for the next higher pressure range.

2. Minimum level of OH$^-$ alkalinity in boilers below 6.21 MPa (900 psig) must be individually specified with regard to silica solubility and other components of internal treatment.

3. Maximum total alkalinity consistent with acceptable steam purity. If necessary, should override conductance as blowdown control parameter. If makeup is demineralized water at 4.14 MPa (600 psig) to 6.89 MPa (1000 psig), boiler water alkalinity and conductance should be that in table for 6.90 to 10.34 MPa (10001 to 1500 psig) range.

4. Not detectable in these cases refers to free sodium or potassium hydroxide alkalinity. Some small variable amount of total alkalinity will be present and measurable with the assumed congruent or coordinated phosphate-pH control or volatile treatment employed at these high pressure ranges.

5. Maximum values often not achievable without exceeding suggested maximum total alkalinity values, especially in boilers below 6.21 MPa (900 psig) with >20% makeup of water whose total alkalinity is >20% of TDS naturally or after pretreatment by lime-soda, or sodium cycle ion exchange softening. Actual permissible conductance values to achieve any desired steam purity must be established for each case by careful steam purity measurements. Relationship between conductance and steam purity is affected by too many variables to allow its reduction to a simple list of tabulated values.

6. Nonvolatile TOC is that organic carbon not intentionally added as part of the water treatment regime.

7. Boilers below 6.21 MPa (900 psig) with large furnaces, large steam release space and internal chelant, polymer and/or antifoam treatment can sometimes tolerate higher levels of feedwater inpurities than those in the table and still achieve adequate deposition control and steam purity. Removal of these inpurities by external pretreatment is always a more positive solution. Alternatives must be evaluated as to practicality and economics in each individual case.

8. Values in table assume existence of a deaerator.

9. No values given because steam purity achievable depends upon many variables, including boiler water total alkalinity and specific conductance as well as design of boiler, steam drum internals, and operating conditions (Note 5). Since boilers in this category require a relatively high degree of steam purity, other operating parameters must be set as low as necessary to achieve this high purity for protection of the superheaters and turbines and/or to avoid process contamination.

makeup, blowdown, and feedwater flows. In performing heat balance, losses due to radiation should also be included. Normally, these losses amount to approximately 1% of the total boiler heat input.

The heat available for steam generation is the heat lost by the flue gas less the heat lost by boiler radiation. This heat is absorbed by and stored in steam, blowdown, and feedwater. Referring to Figure 5-2:

Waste heat = heat in steam + heat in blowdown - heat in feedwater

Heat in blowdown = WBDN x h_{bdn}

Heat in feedwater = WFW x h_{fw}

Heat in steam = STOT x h_{stm}

STOT = WFW-WBDN

Where:

WBDN = Blowdown rate, kg/h
h_{bdn} = Enthalpy of blowdown, kJ/kg

WFW = Feedwater rate, kg/h
h_{fw} = Enthalpy of feedwater, kJ/kg

STOT = Steam generation rate, kJ/h
h_{stm} = Enthalpy of steam, kJ/kg

Usually the blowdown rate is given as a percentage of the feedwater flow.

To calculate steam required for feedwater heating, makeup, and condensate return flows, a material balance and a heat balance must be performed around the deaerator.

Material (flow) balance:

$$WFW = SHTG + WRTN + WRAW$$

Where:

SHTG = Steam supply rate for feedwater heating, kg/h
WRTN = Condensate return rate, kg/h
WRAW = Makeup water rate, kg/h

Heat balance:

$$WFW x h_{fw} = SHTG x h_{stm} + WRTN x h_{ret} + WRAW x h_{mu}$$

Where:

h_{ret} = Enthalpy of condensate return, kJ/kg
h_{mu} = Enthalpy of makeup water, kJ/kg

If condensate is not returned to the boiler, the steam required for feedwater heating will increase and:

$$SHTG = WFW-WRAW$$

In this case, 12 to 15% of the generated steam is required to heat the makeup water.

Use of condensate return for makeup water heating increases the quantity of steam available for process use. The flow of steam (SNET) is available for useful work.

To calculate available heat for steam generation, the temperature of flue gas exiting the boiler section and entering the air emission control system can be assumed to be in the range of 180°C to 290°C (about 350°F to 550°F).

5.4 DESIGN CONSIDERATIONS

5.4.1 Materials Selection

Normally, ash, inorganic salt compounds, chlorinated and sulphur compounds, and phospho-organics are present in waste incinerator flue gases and deserve special consideration in the design of waste heat boilers. The combination of acidic gases and low-melting-point inorganic salts represents the most severe condition for an energy recovery system.

At sufficiently high temperatures, molten salts and oxides, when cooled, solidify on the waste heat boiler tubing causing fouling, corrosion, and reduced efficiency in the boiler. Ash from waste incineration generally has a high concentration of alkali metal salts and other compounds, such as $NaCl$, Na_2O, $NaFe(SO4)_2$, and $ZnCl_2$, which have melting points well below 800°C (1472°F). In addition, the possible formation of eutectic mixtures (complex combinations of salts with melting points lower than pure salts) will further depress the melting point of the ash. Melting points of some salts and oxides are shown in Table 5-2.

Combustion of phospho-organics results in the formation of gaseous P_2O_5. Above 599°C (1110°F), P_2O_5 reacts with deposits on waste-heat boiler surfaces and with iron oxide on the boiler wall, resulting in difficult-to-remove incrustations. This causes corrosion and reduces boiler life and efficiency.

The molten salts problem can be alleviated by cooling the incinerator exhaust gas below the salt melting point before it enters the waste heat boiler; this can be accomplished by quenching it with water, adding ambient air, or combining it with recycled gas from the boiler exhaust. However, reducing the flue gas temperature will reduce the waste heat boiler's efficiency and decrease its steam production capacity.

Table 5-2
Melting Points of Some Salts and Oxides
Present in Incinerators

Component, Mole Fraction	°C	°F	Remarks
P_2O_5	569	1056	
$0.50NaCl--0.26Na_2SO_4--0.24Na_2CO_3$	612	1134	Tertiary eutectic
$0.65Na_2SO_4--0.35NaCl$	623	1153	Binary eutectic
$0.62Na_2CO_3--0.38NaCl$	633	1172	Binary eutectic
NaCl	801	1474	
Na_2SO_4	884	1623	
Cu_2O	1236	2257	
Fe_2O_3	1462	2664	Decomposition
Fe_2O_3	1560	2826	Decomposition

Incineration of chlorinated organic compounds produces HCl and some Cl_2 as combustion products. HCl forms hydrochloric acid which is extremely corrosive to metal heat-transfer surfaces when the flue gas temperature is below the HCl dew point temperature of about 150°C (300°F). On the other hand, if the temperature of the metal surface is above 340°C (650°F), high temperature corrosion of the metal surface will occur. The presence of dry hot Cl_2 will also cause severe corrosion.

Combustion of sulphur-containing waste yields SO_2 and SO_3 in the incinerator flue gases. As with HCl, condensation of sulphuric acid and sulphurous acid from the reaction of SO_2 and SO_3 with water vapour is possible.

Therefore, the corrosive/erosive nature of the ash and the presence of acid gas in the flue gas are critical considerations in the selection of operating temperatures (particularly the waste heat boiler outlet temperature) and in selection of materials of construction for the waste heat boilers. These considerations should be addressed on a case-by-case basis, depending on the particular waste being incinerated.

5.4.2 Design Features

In general, flue gas characteristics will dictate the type and design of the waste heat recovery boiler to be used in a specific incineration heat recovery application.

When only acid gases are present in the flue gas, either a fire tube or water tube boiler can be used. In the case of low-concentration, low-melting-point salts only, a specifically designed water tube boiler may be satisfactory. When both acid gases and salts are present, a radiant/convective boiler is necessary.

5.4.2.1 Fire Tube Boilers

In fire tube boilers, the high-temperature flue gases flow through the inside of a tube bundle section, transferring heat to the pressurized water that surrounds the outside of the tube bundle. The steam generated is discharged into a steam drum through several riser pipes. This type of boiler can be used for hot gases under high pressure. Fire tube boilers are generally limited to maximum steam pressures of 10 MPa (1,500 psig).

In this type of boiler, erosion of the tubes can be minimized by controlling the flue gas velocity below 15 m/s (40 ft/sec). In fire tube boilers, the inside of the tubes cannot be cleaned during the operation; the buildup resulting from the presence of low-melting-point compounds inside the tubes generally precludes their use in this application.

5.4.2.2 Water Tube Boilers

In water tube boilers, the high-temperature, flue-gas flow on the outside of the tubes transfers heat to the pressurized water inside. This type of boiler can be used from relatively low pressure to supercritical steam applications. Water tube boilers can be designed in a very wide range of sizes; moreover, it takes only one-third (or less) the time required by fire tube units to reach full steam generating capacity. Since the tubes in water tube boilers have one or more bends, they have more flexibility for thermal expansion.

To control erosion of the boiler housing from the flue gas ash particles, certain flue gas velocity limitations should be observed. The limiting velocity depends on the ash particle content of the flue gas; however, a velocity limit of 12 to 18 m/s (40 to 60 ft/sec) is generally observed.

Water tube boilers may be used for waste heat recovery from the incineration of a selected waste profile that produces particulates with relatively low sticking and fusion characteristics. Such boilers should be equipped with efficient soot-blowing mechanisms to allow cleaning of the heat transfer surface during the boiler operation.

5.4.2.3 Radiant/Convective Boiler

Waste heat recovery from "dirty" flue gas containing both acid gases and sticky, low-melting-point particulate is accomplished in radiant/convective-type boilers. The heat transfer surfaces are the boiler walls and internal baffles, which consist of vertical tubes welded together along their lengths to form a continuous heat transfer membrane. Water is force-circulated upward through the tubes and the generated steam is separated in a steam drum. The baffles (tube membranes) are placed perpendicular to the flow of the flue gas as it exits the incinerator, and they are arranged to provide several flue gas passes.

About one-half of the recoverable energy is removed from the flue gases in the radiant cooling chamber. The flue gas then enters the convective section of the boiler across the baffles where further cooling of the flue gas and ash particles takes place. To reduce erosive effects of ash particles, flue gas velocities in the convective section are in the range of 10 to 15 m/s (35 to 50 ft/sec).

Generally, in the last convective pass of the boiler, additional water tubes can be installed to increase the heat transfer efficiency. In a clean boiler, most of the heat transfer takes place in the first one-third section of the unit; however, as fouling progresses, steam generation is shifted from the forward section to the downstream heating surfaces of the boiler.

Chapter 6
EMISSIONS CONTROL

6.1 INTRODUCTION

Incineration generates air emissions, ash, or solid residues and, depending on the specific incineration process system used, may produce a wastewater. These discharges will be significantly less in quantity than the initial waste stream provided that the incinerator has been properly designed and operated. In this chapter, the treatment of incinerator discharges is discussed.

6.2 AIR EMISSIONS

6.2.1 Contaminants

The more common air pollutants discharged from incinerators include the following:

- Particulate matter inclduing metals
- Inorganic gases
- Organic gases
- Acid gas
- Odour
- Noise

The generation of each of these pollutants is discussed in the following subsections.

The standards governing atmospheric discharges are set out under Regulation 308 of the Environmental Protection Act (See pg. 2-4 and 2-5 for details). Table 6-1 lists the current standards, tentative standards, guidelines, and provisional guidelines as of March 15, 1988. The table is

Table 1
List of Ambient Air Quality Criteria, Standards, Tentative Design Standards, Guidelines and Provisional Guidelines as of 15 March 1988

Contaminant	POI .5h Av ug/m³	AAQC 24h Av ug/m³	LE	ST
Acetic Acid	2500	2500	O	S
Acetylene	56000	56000	O	S
Acrolein	28	23.5	H	TS
Acetone	48000	48000	O	S
Acrylamide	45	15	H	S
Acrylonitrile *	2200	750	H	S
Acrylonitrile	300	100	H	TS
n-alkyltoluenesulphonamide	100	120	T	PG
Alpha Naphthol	100	100	H	G
Aluminum Oxide	100	120	T	PG
Ammonia	3600	3600	O	S
Ammonium chloride	100	120	T	PG
Antimony	75	25	H	S
Arsenic *	75	25	H	S
Arsenic	1	.3	H	TS
Arsine	10	5	H	S
Asbestos	5 #	0.04 9	H	G
Barium-total water soluble	30	10	H	G
Benzene	10000	3300	H	S
Benzo(a)pyrene	3.3 16 ss	0.3 16,6 ss	H	PG
		1.1 16,ss		
		0.22 16,6,ss		
Benzothiazole	200	70	H	PG
Benzoyl Chloride	350	125	C,H	PG
Beryllium	0.03	0.01	H	S
Biphenyl	60	60 1	O	G
Boron Tribromide	100	35	C	S
Boron Trichloride	100	35	C	S
Boron Trifluoride	5	2	V	S
Boron	100	100	T	S
Bromacil	30	10	H	G
Bromine	70	20	H	S
n-Butanol		15000 1	I	PG
	2278	3100 18	O	PG
		770	O	PG
n-Butyl Acetate*	15000	15000	I	PG
n-Butyl Acetate		15000 1	H	PG
	735	1000 18	O	PG
		248	O	PG
Butyl Acrylate	100	100	T	G
Butyl Stearate	100	14000	T	G
Cadmium	5	2	H	S
Calcium Carbide	20	10	W	PG
Calcium Cyanide @@	100	100	T	PG
Calcium Hydroxide	27	13.5	C	S
Calcium Oxide	20	10	C	S
Captan	75	25	H	PG
Carbon Black	25	10	S	S
Carbon Disulphide	330	330	O	S

Table 1 (Cont'd)

Carbon Monoxide	6000	36200 1	H	S
		15700 2	Z	S
Carbon Tetrachloride*	20000	7000	H	S
Carbon Tetrachloride	1800	600	H	G
Chloramben	100	120	T	PG
Chlordane	15	5	H	G
Chlorinated Dibenzo Dioxins, CDDs	450 17	30 17,6	H	PG
Mixtures of Chlorinated Dibenzo Dioxins and Chlorinated Dibenzo Furans, CDFs				
	x/450 + y/450(50) = 1	x/30 + y/30(50) =1 (annual average)	H	PG
x=concentration (pg/m3) of CDDs in air				
y=concentration (pg/m3) of CDFs in air				
Chlorine	300	150	H,V	S
Chlorine Dioxide	85	30	H	S
Chlorodifluoromethane	1.05M	350000	H	PG
Chloroform	1500	500	H	G
Chromium *	30	10	H	S
Chromium (Di, Tri, and Hexavalent forms)	5	1.5	H	PG
Coal Tar Pitch Volatiles	3	1	H	PG
(soluble fraction)		0.2 6		PG
Copper	100	50	H	S
Cresols	230	75	H	S
Cyclo Sol 63	25000	5000	H	PG
Cyclohexane	300000	100000	H	G
Dalapon Sodium Salt	100	50	H	G
Decaborane	50	25	H	S
Decene-1	180000	60000	H	PG
Detergent Enzyme (Subtilisin) *	1	0.3	H	S
Detergent Enzyme	0.20	0.06	H	TS
Diacetone Alcohol	990	1350 18	O	PG
		335	O	PG
Diazinon	9	3	H	G
Diborane	20	10	H	S
Dibutyltin Dilaurate	100	30	H	G
3,3-Dichlorobenzidine	-	-	H	CAR
Dicapryl Phthalate	100	500	T	S
Diisobutyl Ketone		3500	H	PG
	470	649 18	O	PG
		159	O	PG
Difluorodichloromethane (Freon 12)	1.5M	500000	H	PG
Dimethyl Disulphide	40	40 1	O	S
n,n-dimethyl-1,3-diaminopropane	60	20	H	PG
Dimethyl Ether	2100	2100	O	G
Dimethyl Sulphide	30	30 1	O	S
Dioctyl Phthalate	100	500	T	S
Dioxane		3500	H	G
Dioxolane	30	10	H	PG
Dodecyl Benzene Sulphonic Acid	100	100	T	PG
Dodine	30	10	H	PG
Droperidol	3	1	H	PG
Dustfall	8000 @	7.0 3,4	S	S
Ethyl Acetate	19000	19000 1	O	S
Ethyl Acrylate	4.5	4.5 1	O	S
Ethyl Alcohol	19000	19000 1	O	G
Ethyl Benzene	4000	4000 1	O	S
Ethyl Ether	30000	30000	O,H	TS
Ethyl-3-ethoxy propionate	147	200 18	O	PG
		50	O	PG
		6500	H	PG
2-Ethyl Hexanol	600	600 1	O	G

Table 1 (Cont'd)

2-Ethylanthraquinone	30	10		H	PG
Ethylene	160	40		V	TS
Ethylene Dichloride	1200	400		H	PG
Ethylene Glycol Dinitrate	10	3		H	G
Ethylene Glycol Butyl Ether (Butyl Cellosolve)	350	2400		H	PG
		500	18	O	PG
Ethylene Glycol Butyl Ether Acetate (Butyl Cellosolve Acetate)	500	3250		H	PG
		700	18	O	PG
Ethylene Glycol Ethyl Ether (Cellosolve)	800	380		H	PG
		1100	18	O	PG
Ethylene Glycol Ethyl Ether Acetate (Cellosolve Acetate)	220	540		H	PG
		300	18	O	PG
Ethylene Oxide *	28500	9500		H	S
Ethylene Oxide	15	5		H	PG
Ethylenediaminetetra-acetic Acid	100	120		T	PG
Fentanyl Citrate	0.06	0.02		H	PG
Ferric Oxide	75	25		S	S
Fluoridation t,GS		40	4,15	V	G
Fluoridation t,NM		80	4,15	V	G
Fluorides G,%%,GS	4.3			V	S
		0.86		V	G
		0.34	4	V	G
Fluorides t, %%,GS	8.6			V	S
		1.72		V	G
		0.69	4	V	G
Fluorides t,%% NM	17.2			V	S
		3.44		V	G
		1.38	4	V	G
Fluorides in forage		80	11,12	A	G
Fluorides in forage		60	11,13	A	G
Fluorides in forage GS		35	11,14	A	G
Fluorinert 3M-FC-70	100	100		T	PG
Formaldehyde	65	65	1	O	S
Formic Acid	1500	500		H	S
Furfural	1000	1000	1	O	S
Furfuryl Alcohol	3000	1000		H	S
Glutaraldehyde	42	14		H	PG
		35	1		
Haloperidol	0.3	0.1		H	PG
Hexachlorocyclopentadiene	6	2		H	PG
Hexamethyl Disilazane	5	2		H	PG
Hexamethylene Diisocyanate Monomer	1.5	0.5		H	PG
Hexamethylene Diisocyanate Trimer	3	1		H	PG
Hexane	35000	12000		H	G
Hexylene Glycol	14400	12000		H	TS
Hydrogen Chloride	100	40		C	S
Hydrogen Cyanide	1150	575		H	S
Hydrogen Peroxide	90	30		H	PG
Hydrogen Sulphide	30	30	1	O	S
Isobutanol	1940	2640	18	O	PG
		655		O	PG
		15000	1	H	PG
Isobutyl Acetate	1220	1660	18	O	PG
		412		O	PG
		12700		H	PG

Table 1 (Cont'd)

Isopropyl Acetate	1470		2000	18	O	PG
			500		O	PG
			19000		H	PG
Iron (Metallic)	10		4		S	S
Isopropyl Alcohol	24000		24000		O	G
Isopropyl Benzene	100		100	1	O	PG
Lead	10				H	S
			3	4,5	H	G
			2	4,7	H	G
			5	8	H	G
Lead in Dustfall	0.1	3,4	-		H	TS
Lindane (Hexachloro-cyclohexane)	15		5		H	PG
Lithium Hydrides	7.5		2.5		H	S
Lithium (other than hydrides)	60		20		H	S
Manganese Compounds 11	30		10		H	PG
Magnesium Oxide	100		100		T	S
Malathion	100		300		T	G
Maleic Anhydride	100		30		H	G
Manganese*	100		50		T	S
Manganese	7.5		2.5		H	S
Mercaptans (as methyl mercaptan)	20		20	1	O	S
Mercapto benzo thiazo disulphide	100		100		T	G
Mercury (alkyl)	1.5		0.5		H	S
Mercury	5		2		H	S
Metaldehyde	100		9000		1	PG
			120		T	PG
Methacrylic Acid	2000		2000		O	G
Methane diphenyl di-isocyanate (methylene bisphenyl isocyanate)	3		1		H	TS
Methoxychlor	100		100		T	G
5-methyl-2-hexanone	460		630	18	O	PG
			160		O	PG
			4600		H	PG
Methylal	18000		6200		H	PG
Methyl Acrylate	4		4	1	O	S
Methyl Alcohol	84000		28000		H	S
Methyl Bromide *	12000		4000		H	S
Methyl Bromide	4000		1350		H	G
Methyl Chloride	20000		7000		H	G
Methylcyclopentadienyl Manganese Tricarbonyl (MMT)	30		10		H	S
Methyl Ethyl Ketone (2-Butanone)	31000		31000	1	O	S
Methyl Ethyl Ketone	250		80		H	G
Peroxide			200	1		G
Methyl Isobutyl Ketone	1200		1200		O	G
Methyl Methacrylate	860		860		O	S
Methyl-N-Amyl Ketone **						G
Methyl Salicylate	300		100		H	G
4,4 Methylene-Bis-2-Chloroaniline	30		10		H	G
Methylene Chloride	100000		100000	1	O	S
Methylene Dianiline	30		10		H	G
Miconazole Nitrate	15		5		H	PG
Milk Powder	20		20		S,O	S
Monomethyl Amine	25		25		O	S
Naphthalene	36		22.5		H	PG
			50	18	O	PG
Nickel	5		2		V	S
Nickel Carbonyl	1.5		.5		H	S
Nitric Acid	100		35		C	S
Nitrilotriacetic Acid	100		100		T	S

Table 1 (Cont'd)

Nitroglycerin	10		3		H	G
Nitrogen Oxides (as NO_2)	500		200		H	S
Nitrous Oxide	27000		9000		H	PG
N-Nitrosodiethylamine	-		-		H	CAR
N-Nitrosodimethylamine	-		-		H	CAR
Octane	45400		61800	18	O	PG
			15300		O	PG
			145000		H	PG
Octene-1	150000		50000		H	PG
Oxalic Acid	75		25		H	PG
Ozone	200		165	1	H,V	S
Palladium (H_2O sol.) ##	30		10		H	PG
Penicillin	0.3		0.1		H	G
Pentaborane	3		1		H	S
Pentachlorophenol *	90		30		H,V	S
Pentachlorophenol	60		20		H	G
Perchloroethylene	10000		4000		H	G
Phenol	100		100		O	S
Phosgene	130		45		H	S
Phosphine	30		10		H	PG
Phosphoric Acid (as P_2O_5)	100		100		H,T	S
Phosphorus Pentachloride	30		10		H	G
Phosphorus Oxychloride	40		12		H	PG
Phthalic Anhydride	100		100		T	S
Pimozide	3		1		H	PG
Platinum in water soluble compounds %	0.6		0.2		H	G
Polybutene-1-Sulphone	100		100		T	PG
Polychlorinated	450	16	150	16	H	G
Biphenyls (risk: .84/m)			35	16,6,10		G
Polychloroprene	100		500		T	G
Potassium Cyanide @@	100		100		T	PG
Potassium Hydroxide	28		14		C	PG
Potassium Nitrate	100		100		T	G
Propionaldehyde	7		10	18	O	PG
			2.5			
Propionic Acid	100		100	1	O	G
Propionic Anhydride (exressed as propionic acid)	100		100	1	O	G
n-Propyl Alcohol	48000		16000		H	G
Propylene Dichloride	2400		2400		O	S
Propylene Glycol Mono-methyl Ether Acetate	5000		5000		O	PG
Propylene Glycol Methyl	89000		121000	18	O	PG
Ether			30000		O	PG
Propylene Oxide*	78000		26000		H	S
Propylene Oxide	13500		4500		H	PG
Pyridine			150		H	PG
	60		80	18	O	PG
Selenium	20		10		H	G
Silane	450		150		H	PG
Silica-respirable (d<10 um)	15		5		H	G
Silver	3		1		H	S
Sodium Bisulphite	100		120		T	PG
Sodium Chlorite	60		20		H	PG
Sodium Cyanide @@	100		100		T	PG
Sodium Hydroxide	20		10		C	PG

Table 1 (Cont'd)

7 Solvesso 100			1250		H	PG
	1250		1700	18	O	PG
			422		O	PG
Solvesso 150			2750		H	PG
	1250		1700	18	O	PG
			422		O	PG
Stannous Chloride (as Tin)	30		10		H	PG
Strontium	100		120		T	TS
Strontium Oxide	100		120		T	TS
Strontium Hydroxide	100		120		T	TS
Strontium Carbonate	100		120		T	TS
Styrene	400		400		O	S
Sulphation	0.7	19			X	G
Sulphur Dioxide	830		275		H,V	S
			690	1		S
			55	6		S
Sulphuric Acid	100		35		C	S
Suspended Particulate	100		120		H	S
Matter (d<44 um)			60	6,7		S
Talc (fibrous)	5		2		H	G
Tellurium (except hydrogen telluride)	30		10		H	S
Tetrabutylurea	30		10		H	PG
Tetrahydrofuran	93000		93000		O	S
Tetramethyl thiuram disulphide	30		10		H	G
Thiourea	60		20		H	PG
Tin	30		10		H	S
Titanium	100		100		T	S
Tolmetin Sodium	15		5		H	PG
Toluene	2000		2000		O	S
Toluene Di-isocyanate	1		0.5		H	S
Total Reduced Sulphur (TRS) as equivalent H2S (from Kraft Pulp Mills)	40		40	1	O	PG
1,2,4-Trichlorobenzene	100		400		T	G
1,1,1-Trichloroethane (methyl chloroform)	350000		115000		H	S
Trichloroethylene	85000		28000		H	S
Trifluorotrichloro Ethane	2.4M		800000		H	S
Trimethyl Amine	0.5		0.5	1	O	G
1,2,4-Trimethylbenzene	100		1000		T	G
Tripropyltin Methacrylate	3		1			G
Vanadium	5		2		H	S
Vinyl Chloride	560		280		H	G
Vinylidene Chloride * (1,1-Dichloro Ethene)	26000		8600		H	S
Vinylidene Chloride	70		35		H	PG
Warfarin	30		10		H	G
Whey Powder	100				T	PG
Xylenes	2300		2300		O	S
Zinc	100		100		T	S

DEFINITIONS FOR ABBREVIATIONS IN LIST OF STANDARDS, TENTATIVE STANDARDS, GUIDELINES, AND PROVISIONAL GUIDELINES

A - Effects on Animals
C - Corrosion
CAR - Carcinogen with no assigned standard or guideline value. Emissions to the environment must be prevented or limited to the greatest extent possible.
G - Gaseous
H - Health
I - Irritant property
M - Million
O - Odour
P - Particulate
S - Soiling
as - All Sources
ss - Single Source
t - Total
T - TSP (total suspended particulate) standard
V - Vegetation
W - Corrosivity of reaction product with water
X - SO_2 activity
Z - High background levels from automobiles

GS - Growing season
May 1 - September 30 - NE & NW regions
April 1 - September 30 - other regions
NM - October 1 - March 31

!! - Including Potassium Permanganate as Manganese
@ - ug/m2
@@ - As total salt
# - Total Asbestos
- Water soluble forms including Palladium Chloride as Palladium
% - Including Hexachloroplatinic Acid as Platinum
%% - As HF
* - changed, lowest value in effect
** - under review, for details see contact

1 - 1 hour
2 - 8 hour
3 - g/m^2
4 - 30 day
5 - arithmetic mean
6 - 1 year
7 - geometric mean
8 - single sample
9 - fibres per cc, of length > 5um
10 - average
1 - ppm
12 - dry weight, any single month
3 - dry weight, average of 2 consecutive months

14 - dry weight, average of monthly results for growing season
15 - ug total fluorides/100 cm^2 limed paper
16 - ng/m^3
17 - pg/m^3
18 - 10 minute
19 - mg SO_3/100 cm^2/day

POI - Point of Impingement - ug/m^3
AAQC - Ambient Air Quality Criterion - ug/m^3
LE - Limiting Effect
ST - Type of Standard :
S - Standard, appears in O.R.308
TS - Tentative Design Standard, set by EASSC
G - Guideline, set by EASSC
PG - Provisional Guideline, set by EASSC

EASSC-Environmental Air Standards Setting Committee

a - average
cm - centimetre
cm^3 - cubic centimetre
cm^2 - square centimetre
d - days
g - gram
h - hour
m^3 - cubic metre
mg - milligram - 10-3 g
m^2 - square metre
ng - nanogram - 10-9 g
pg - picogram - 10-12 g
ppm - parts per million
ug - microgram - 10-6 g
um - micrometre
y - year

Computation of values for various averaging times for standards and guidelines based on the limiting effect of odour, for continuous sources following classical plume behaviour.

$$C = OT(0.t)^{-.28047}$$

where: OT = odour threshold, 50% detection level
t = time in minutes

contact: For additional information contact Emission Technology and
Regulation Development Section, Air Resources Branch,
Ontario Ministry of the Environment
416-965-5776

continually being updated and the reader should check with the Ministry to determine the current status of this information.

Policy 01-03 and its interim guideline (see Appendix B) relate to the use of state-of-the-art air pollution control, and include particulate and hydrogen chloride emission limits from refuse incinerators.

6.2.1.1 Particulate Matter

The most visible discharge from a burning process is smoke. Smoke and other particulate matter, or aerosols, are defined by size, as shown on Figure 6-1. One micron, μ, is one-millionth of a metre and is commonly used to describe particulate size. Smoke is a suspension of solid or liquid particulate matter in a gaseous discharge. The particles range from fractions of a micron to over 50 microns in diameter. The visibility of smoke is related to the quantity of particles present, rather than to the weight of the particulate matter. The weight of particulate emissions is, therefore, not necessarily indicative of the density of the emission. Neither is the colour of a discharge related to opacity or smoke density. Smoke can be black or can appear nonblack; in the latter case, it is termed "white smoke." These two types of smoke are discussed below:

- White smoke: The formation of white or other opaque, nonblack smoke is usually due to insufficient furnace temperatures when burning carbonaceous materials. Hydrocarbons will be heated to a level where evaporation and/or cracking will occur within the furnace when white smoke is produced. The temperatures will not be high enough to produce complete combustion of these hydrocarbons. With a stack temperature in the

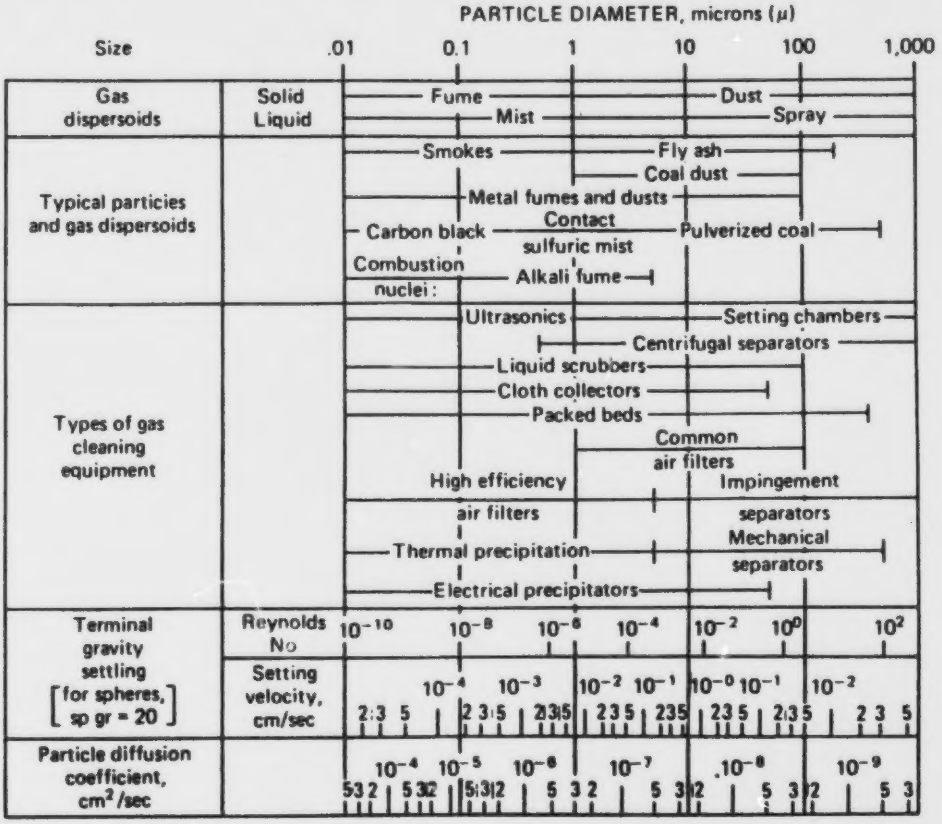


Figure 6-1

PARTICULATE MATTER BY SIZE

SOURCE : FROM CHEMICAL ENGINEER'S HANDBOOK, R. PERRY, C. CHILTON, FIFTH EDITION, McGRAW HILL 1973, PAGE 20-79

range of 150°C to 260°C (300°F to 500°F), many of these hydrocarbons will condense to liquid aerosols; with solid particulate present, these will appear as nonblack smoke.

A method for controlling white smoke is to increase the furnace/stack temperatures and increase turbulence to help ensure uniformity of this hig temperature within the off-gas flow.

Excessive airflow may result in excessive cooling. An evaluation of reducing white smoke discharges should include investigating the air quantity introduced into the furnace. Inorganics in the exit gas may also produce a nonblack smoke discharge. For instance, sulphur and sulphur compounds will appear yellow in a discharge; calcium and silicon oxides in the discharge will appear light to dark brown.

- Black smoke: When burned in an oxygen-deficient atmosphere, hydrocarbons will not completely destruct, and carbon particles will be found in the off-gas. Causes of local oxygen deficiency include poor atomization, inadequate turbulence (or mixing), and poor air distribution within a furnace chamber. Each of these factors will generate carbon particles that produce dark, black smoke in the off-gas.

  A common method of reducing or eliminating black smoke has been steam injection into the furnace. The carbon present is converted to methane and carbon monoxide as follows:

$3C \text{ (smoke)} + 2H_2O \rightarrow CH_4 + 2CO$

Hydrocarbons react similarly, and the methane and carbon monoxide produced burn clean in the heat of the furnace, eliminating the black carbonaceous smoke that would have been produced without steam injection:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \text{ (smokeless)}$

$2CO + O_2 \rightarrow 2CO_2 \text{ (smokeless)}$

Steam injection normally requires from 9 to 40 kg (20 to 80 pounds) of steam per pound of flue gas.

It should be noted that there is some controversy regarding the effect of steam injection into carbonaceous discharges. Some argue that the steam primarily produces good mixing.

Metallic particulate discharges into the atmosphere generally account for less than 1% of the total particulate discharge. However, many of these metals generate compounds that can have severe, toxic effects.

6.2.1.2 Inorganic Gases

Inorganic gases produced from the burning process normally include water vapour, carbon dioxide, carbon monoxide, oxides of nitrogen, and, when sulphur is present, oxides of sulphur.

Nitrogen is an extremely active substance that forms nitrogen oxide (NO) and nitrogen dioxide (NO_2) from the combustion process.

Sulphur is released into the atmosphere from burning processes in the form of sulphur dioxide, SO_2, and sulphur trioxide, SO_3.

6.2.1.3 Organic Gases

Of the many organic discharges from incinerators, the more significant ones are:

- Oxygenated hydrocarbons, which include aldehydes, ketones, alcohols, and acids. In sufficient quantity they will produce eye irritation, reduce visibility in the atmosphere, and react with other components of the atmosphere to form additional pollutants. Many of these compounds are also odourous.

- Halogenated hydrocarbons, such as carbon tetrachloride, perchloroethylene, etc. These may contribute to atmospheric clarity problems and may also generate odour.

- Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF). These compounds may be formed when materials containing chlorine are incinerated. These compounds are of considerable concern due to their toxicity in trace quantities to laboratory animals.

- Olefins, which are a group of unsaturated hydrocarbon compounds that readily react with many other chemical compounds. Olefins take part in photochemical reactions in the presence of nitrogen oxides and several other pollutants.

- Aromatics, including benzene, toluene, xylene, and polycyclic aromatic hydrocarbons (PAH). One of the most toxic of these occurring in industrial processes is benzo(a)pyrene (also written as 3,4,benzopyrene). This compound is relatively simple to detect. A primary source of these compounds is the incomplete combustion of organic materials.

The most apparent effect of organic gas discharges is their effect on the atmosphere. They react with other elements of the atmosphere to form photochemical smog, which is as much a danger to health as it is to the aesthetic quality of an area.

6.2.1.4 Acid Gas

Industrial waste will often have either a halogen or sulphide component. Municipal wastes have relatively high proportions of plastics, and many of these materials have a significant amount of chlorides. Chlorides and/or sulphides in an incinerator charge will produce hydrogen chloride and/or chlorine, and sulphur dioxide/trioxide gas in the exhaust stream. Acid gas neutralization systems should be provided when significant quantities of hydrogen chloride are present in an exhaust. Control of these emissions is often necessary for the protection of downstream equipment.

6.2.1.5 Odour

Odours associated with incineration are normally organic and result from the incomplete combustion of organic matter in the waste feed. The most effective means of dealing with the problem of odour generation is alteration of the burning process to increase burning efficiency, thereby decreasing the occurrence of odour-causing compounds in the exhaust stream.

Since waste streams vary in chemistry or quality, the efficiency of the waste-burning process can also change, and combustion parameters must be adjusted to reduce the possibility of odour generation.

Secondary odours may originate from equipment and systems within the incinerator facility such as storage tanks, waste storage pits, etc. Where practical, ventilation systems should be designed to contain such odours and to bring the odourous air to the incinerator for destruction. Other mechanisms of odour control may be required, such as fume incineration, use of a packed tower (absorber), catalytic oxidation system, adsorbtion (using carbon on silicon beds), dilution, or masking.

6.2.1.6 Noise

Noises generated by an incineration facility are generally those resulting from the movement of air or gas. Fans and blowers will create the greatest noise levels; of secondary concern is the noise generated by passage of air or gas through ducts, flues, and nozzles.

In addition to local noise, sound can be broadcast to areas surrounding the plant outside the facility limits. Table 6-2 lists typical sound levels encountered in the course of a day. Broadcast noise can be within the levels listed; however, a fan in constant operation producing a constant drone may become an annoyance and result in a complaint to plant operators.

Local noise can usually be controlled by initial equipment selection, use of sound-absorbing equipment, and provision of sound-deadening or sound-absorbing enclosures around noisy equipment. Exterior noise, however, can be broad-

Table 6-2
Average Single Number Sound Levels, dBA

Interior Noise	
Bedroom at night	30- 40
Small office or store	47- 59
Large store	51- 63
Large office	57- 68
Electric typewriter at 3 m	62- 67
Automobile	64- 78
Garbage disposal	78- 83
Airplane cabine	88- 98
Noises 1 m From Source	
Whispering	30- 35
Quiet ventilating outlet	41- 47
Quiet talking	59- 66
Noisy ventilating outlet	60- 75
Noise 1 m From Source	
Lathe	73- 83
Shouting	74- 80
Power saw	93-101
Power mower	94-102
Farm tractor	94-103
Outside Noises	
Leaves rustling	10- 15
Bird call	40- 45
Quiet residential street	40- 52
Edge of highway with dense traffic	70- 85
Propeller plane at 30 m	75- 84
Pneumatic drill at 15 m	80- 85
Noisy street	84- 94
Jet plane at 300 m	100-105
Jet take-off at 60 m	120-125
37 kW siren at 30 m	130-135

SOURCE: Noise and the Environment, USEPA Journal, October 1979.

cast hundreds of metres, perhaps kilometres. The usual cause of broadcast noise is the pulsation of the ID fan.

Sound control equipment sizing is proportional to the wavelengths of the sound generated. The lower the frequency, the longer the wavelength and the larger the sound control equipment. In controlling ID fan broadcast noise, therefore, it is first necessary to try to increase the beat frequency. If possible, the fan speed should be increased, or if this is impractical, the number of blades should be increased. The ID fan should be close-coupled to the stack. Ductwork with appropriate expansion joints will tend to absorb some of the potential broadcast noise.

Two types of insertion sound control devices are used to reduce broadcast noise. The first is an exhaust silencer, which is placed within the stack or between the ID fan and the stack. These are resonating devices that tend to balance the generated beat by producing (by static geometry) a frequency that is 180 degrees out of phase from the fan beat. The net result, ideally, is cancellation of the beat frequency plus harmonics. The second type is a baffle, usually perforated, that absorbs sound energy with its acoustical fill: fiber glass, mineral wool, or other absorbent.

Standards applicable to noise/sound control are discussed in Section 3.2.4.

6.2.2 Air Emissions Control Devices

Many types of equipment are available for use in controlling air emissions from incinerators. These include the following:

- Inertial systems
- Fabric filters
- Electrostatic precipitators
- Wet scrubbing systems
- Dry scrubbing systems

The following is a discussion of the basic principles and applications for each of these common air emission control devices.

6.2.2.1 Inertial Systems

Inertial systems provide a relatively inexpensive means to remove medium-sized and larger particulate matter from the gas stream (over 15-micron mean particle size). They are normally used in conjunction with other air emission control devices because, alone, they cannot provide sufficient emissions reduction.

Inertial separators operate by the principles of gravitational and/or centrifugal force to remove particulates from the gas stream. Dry inertial systems are effective only with particulate matter and, when properly designed, can provide some noise attenuation. Wet systems can be used to reduce gas or control odours.

Inertial air emissions control systems include the following:

- Settling chambers
- Baffles
- Dry cyclonic separators

- Wet cyclonic separators
- Dry scrubbing

A settling chamber is a stilling chamber where the velocity of a gas is decreased or remains unchanged from the previous process and particles fall from the gas stream by gravity. Settling chambers are used for very large particles, typically 500 microns or greater in size.

Baffles are walls or plates inserted in the gaseous flow stream to act as walls for the flowing particulate matter. The gas stream flows around the baffles; however, the particles, generally above 15 microns, will be stopped by the obstruction and drop to the chamber floor for collection and subsequent removal.

A cyclone is a versatile, low-cost centrifugal separator that can be designed to handle a wide range of chemical and physical conditions of operation. Cyclones are efficient for the removal of larger particles, greater than 15 microns, but are less efficient for removal of smaller particles. The use of a cyclone reduces the particulate loading on downstream equipment. A cyclone separator is often placed upstream of other control devices such as an electrostatic precipitator or a baghouse. Cyclones are designed to operate either in a wet or dry mode.

The dry cyclonic separator separates particulate matter from the gas by transforming the velocity of an inlet stream into a double vortex confined within the cyclone. Particulates within the gas stream move toward the outside wall. The particles drop from the wall inside the cyclone to an external receiver for eventual disposal. One potential problem with the dry cyclonic separator is that some particulate matter may cling to the walls rather than drop down for collection.

Two types of wet cyclonic separators can be used with incineration systems. One is a modification of the dry cyclone in which water is injected at the top of the cyclone to wash the walls free of collected particulate matter. A second type of wet cyclonic separator uses a damper at the entrance to the cyclone. The damper restricts the flow entering the cyclone chamber and imparts a high-velocity spin to the gas stream. Liquid spray is introduced into the rotating gas from an axially located manifold in the lower part of the unit. The atomized fine spray droplets are swept across the walls of the cylinder by centrifugal force and absorb and collect the particulate matter. The spent water generated from either device is collected, treated, and reused or discharged from the system. Examples of typical dry and wet cyclonic separators are presented in Figures 6-2 and 6-3, respectively.

6.2.2.2 Fabric Filters

Fabric filters are commonly used in all types of industrial particulate control applications. The types of filters of interest in incineration applications are the baghouse and the high-efficiency particulate air (HEPA) filter.

Baghouses are the most common air pollution control filtration systems. A typical system is shown in Figure 6-4. The fabric filter material is formed into cylindrical bags, and a series of these bags is suspended within a structure called a baghouse. The dirty gas passes through the permeable fabric, leaving the particulates either on the inside or the outside of the bag, depending on the filtering arrangement. Particles are captured and retained on the fibres of the cloth by means of interception, impingement, diffusion, gravitational settling, and electrostatic attraction.

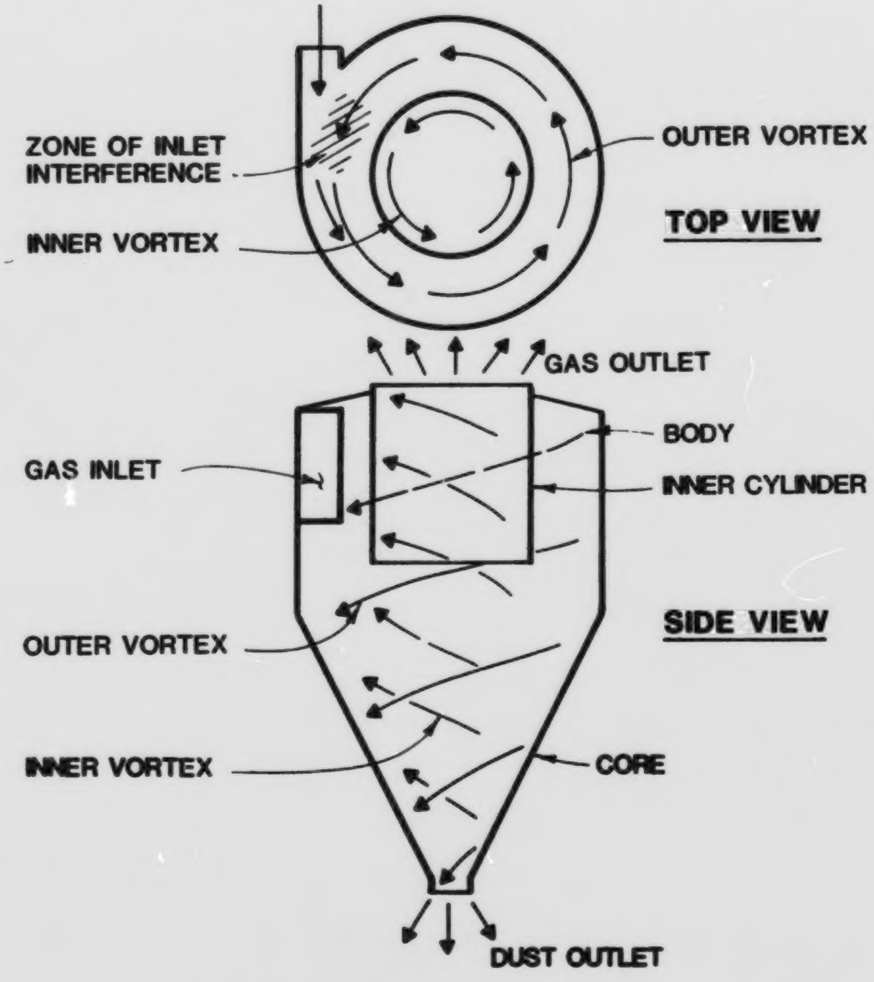

ZONE OF INLET INTERFERENCE
OUTER VORTEX
TOP VIEW
INNER VORTEX
GAS OUTLET
BODY
GAS INLET
INNER CYLINDER
SIDE VIEW
OUTER VORTEX
INNER VORTEX
CORE
DUST OUTLET

Figure 6-2
DRY CYCLONIC SEPARATOR

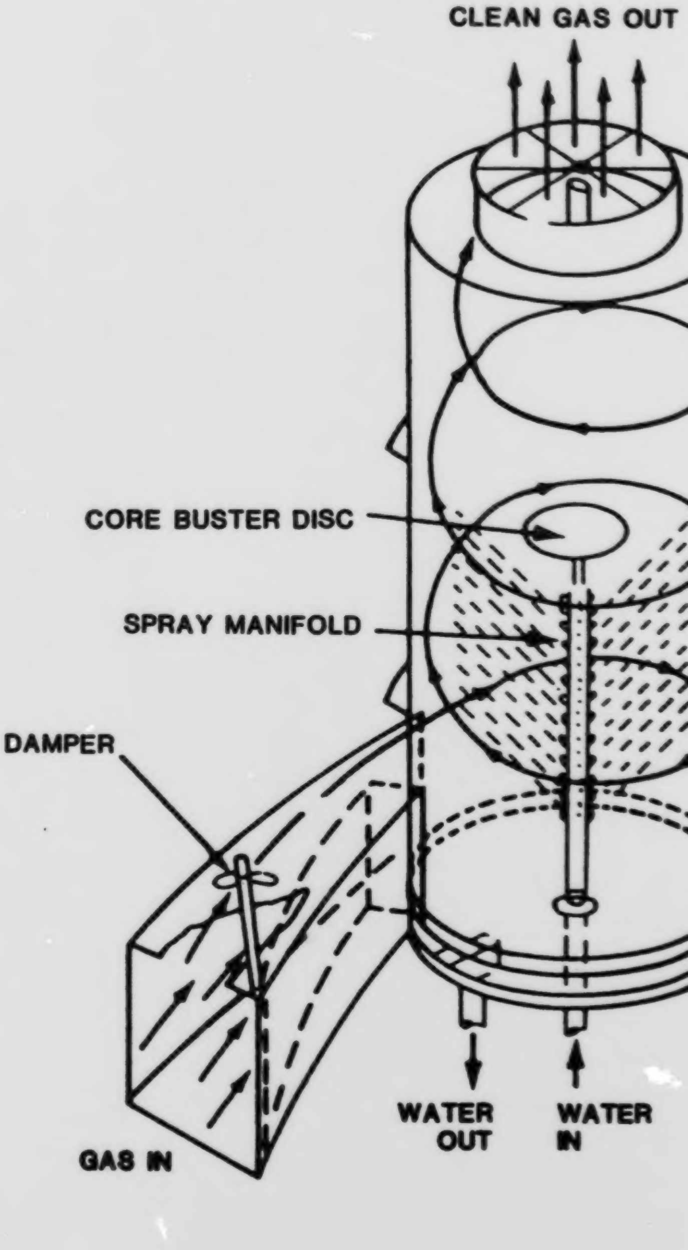

CLEAN GAS OUT
CORE BUSTER DISC
SPRAY MANIFOLD
DAMPER
GAS IN
WATER OUT
WATER IN

Figure 6-3
WET CYCLONIC SEPARATOR

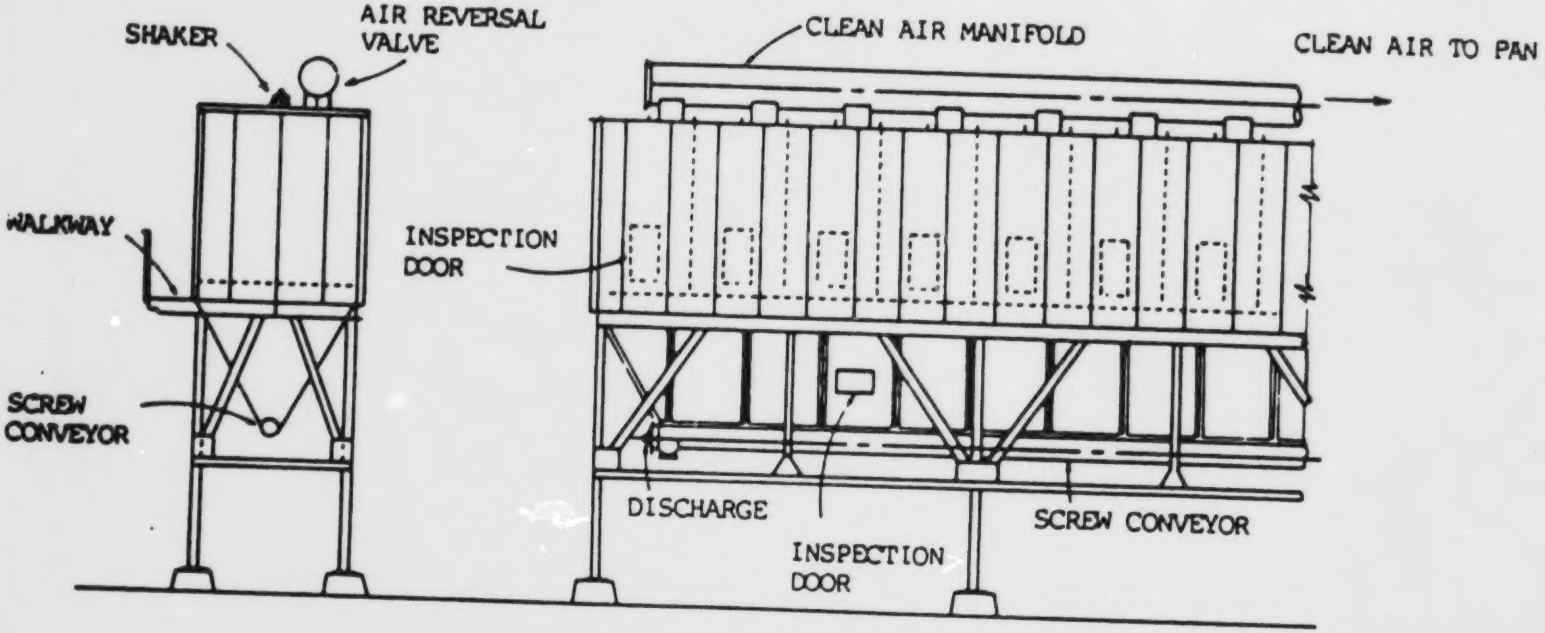

SHAKER
AIR REVERSAL VALVE
CLEAN AIR MANIFOLD
CLEAN AIR TO PAN
WALKWAY
INSPECTION DOOR
SCREW CONVEYOR
DISCHARGE
INSPECTION DOOR
SCREW CONVEYOR

Figure 6-4
TYPICAL BAGHOUSE ASSEMBLY

The filtering media selected for use in a baghouse must be compatible with the temperature and chemical content of the flue gas. In addition, a number of other items must be considered in the selection and design of the baghouse. The baghouse should be designed to provide the degree of filtration required, the longest possible bag life, the ability to properly clean the bags on an automatic and regular basis, and an adequate gas and dust distribution system.

The filter fabric serves as the supporting structure for the dust mat. Periodically, the accumulated dust must be removed for disposal. A major feature of a baghouse is its ability to discharge the accumulated particulate cake; therefore, baghouses are categorized by the type of cleaning method used, as follows:

- Reverse pulse
- Shaker mechanisms
- Reverse flow
- Reverse jet
- Sonic cleaning

Reverse pulse uses a series of strong, short pulses of air that pass through a venturi tube at the top of the bag to exert the cleansing action. The particulate matter builds up on the outside of the bag. After a period of filter cake buildup, reverse air pulses cause the cake to fall off into a hopper for collection and removal.

In a shaker mechanism, an eccentric rod physically shakes the bags, causing the caked particles to fall into the bottom of a silo for eventual removal. Often fresh air is simultaneously admitted to a damper section to aid in the discharge of the collected dust.

In a reverse flow system, baghouses are cleaned by forcing air through the bags in a direction opposite that of normal flow. The reverse flow cleaning air collapses the bag inward; when the bag is brought back online, it expands and dislodges the cake, which falls into a hopper.

The reverse jet system uses a jet manifold that surrounds each bag and continuously moves up and down, blowing the accumulated cake away.

The sonic cleaning method uses an intense sound source that is tuned to create vibration that causes the dust to fall from the bags for collection and eventual removal. It can be used alone or in combination with shaker and reverse air systems.

High-efficiency particulate air (HEPA) filters are used where removal of small particulate matter is required such as incinerators firing low level nuclear-contamined waste streams. HEPA filters are normally used for particle sizes below 2 microns and have excellent removal efficiencies for particle sizes less than one micron. Incinerator exhaust gas streams that have a significant moisture content must pass through a drying system to avoid clogging the filter. In addition, HEPA filters have poor resistance to high temperatures, and incinerator flue gases must be cooled to below 90°C (200°F) for many applications.

A typical HEPA filter, as shown in Figure 6-5, is mounted in a frame. A series of frames is then mounted in a filter bank to provide the required flow capacity.

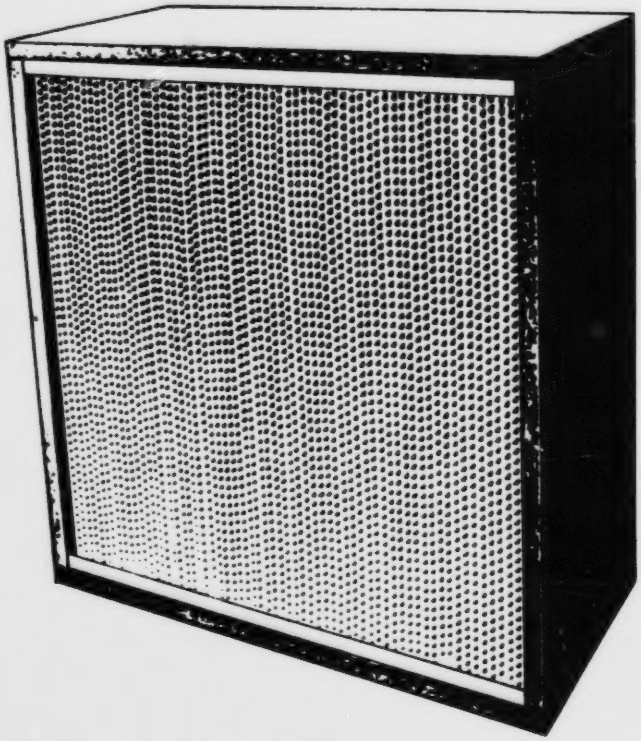


Figure 6-5
HEPA FILTER
(Source : American Air Filter Co., Inc., Louisville, KY)

6.2.2.3 Electrostatic Precipitators

Electrostatic precipitators (ESPs) are effective devices for the removal of airborne particulate matter. Electrostatic precipitation is a process by which particles suspended in a gas are electrically charged and separated from the gas stream under the action of an electric field.

Electrostatic precipitation consists of the following elements:

- Gas ions are formed by means of high-voltage corona discharge.
- Solid or liquid particles are charged by bombardment by the gaseous ions or electrons.
- An electrostatic field causes the charged particles to migrate to a collecting electrode of opposite polarity.
- The charge on the particle is neutralized by the collecting electrode.
- The collected particles are removed from the collecting electrode for subsequent disposal.

Two basic types of ESPs are used for municipal and industrial incinerator emissions control: the conventional ESP and the wet ESP.

The typical conventional (dry) ESP, shown in Figure 6-6, is effective for the collection of fine particles less than one micron in diameter. The efficiency of an ESP is highly sensitive to variations in flue gas temperature and

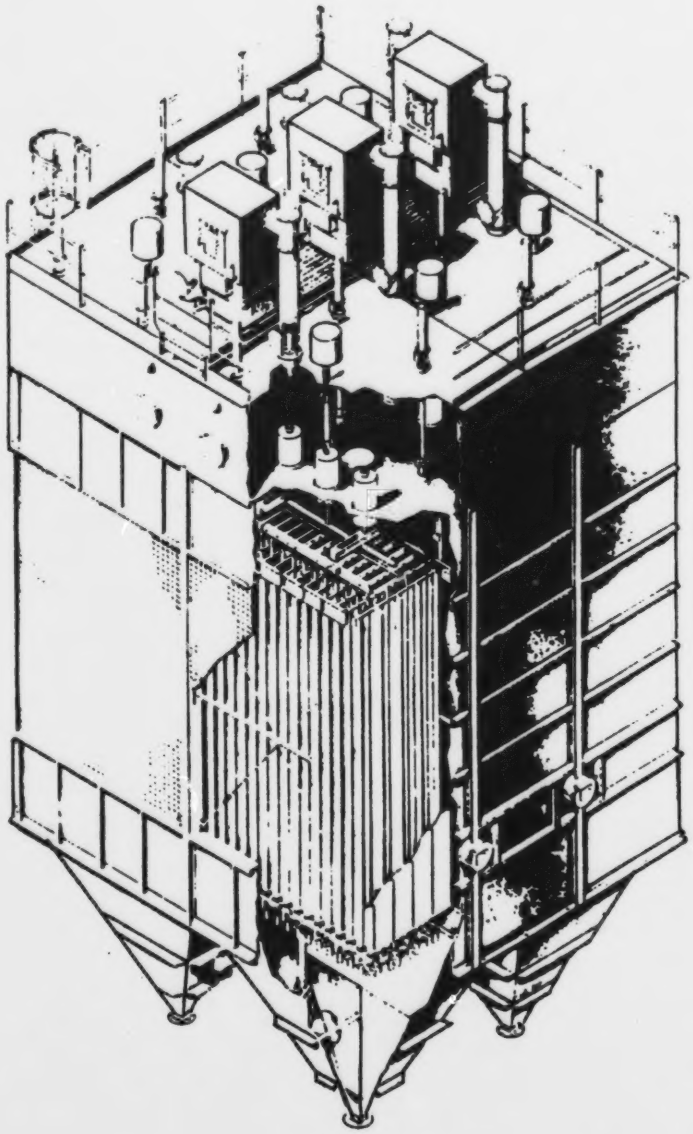


Figure 6-6
TYPICAL ELECTROSTATIC PRECIPITATOR

to humidity, dust concentration, collection area, and resistivity of the particulate matter.

The wet electrostatic precipitator is a variation of the conventional dry ESP design. The two additional features are (1) a preconditioning step in which the entering gas is sprayed with water to reduce its temperature, remove larger particles, and provide some acid gas adsorption; and (2) a wetted collection surface where liquid is used to continuously flush away collected materials.

The wet ESP overcomes some of the limitations of the dry electrostatic precipitator by eliminating the influence of particle resistivity, controlling the buildup of tacky particles, and providing some capacity for removal of gaseous pollutants. A major disadvantage of this system is the generation of a waste liquid stream that must be disposed of.

6.2.2.4 Wet Scrubbing Systems

Wet scrubbers are more universal systems since they can function as particulate and, in some cases, gas and odour control devices. Scrubbers remove particulate matter mainly by inertial impaction and gases by absorption.

Wet scrubbing systems use a scouring action to remove particles from a gas stream. The scrubbing action is primarily a function of particle geometry or physical dimension. Wet scrubbing systems bring particulate matter in contact with liquid droplets that wash the particulates out of the gas stream.

Wet scrubbing systems used for incinerator air emissions include:

- Spray chambers
- Spray towers
- Venturi scrubbers
- Tray scrubbers
- Self-induced scrubbers
- Dry scrubbers

A spray chamber is a simple type of scrubber in which spray nozzles are placed inside a chamber. The gas stream velocity decreases as it enters the chamber, the gas is washed with a liquid, and the wetted particulate matter within the gas is removed with the drained liquid. Spray chambers are used extensively as gas coolers and primarily for removing the heavier particulate matter.

Spray towers remove contaminants by a gas absorption process. The scrubbing liquid is atomized by high-pressure spray nozzles into small droplets, which are then directed into a chamber through which the gas passes. Spray towers are used for simultaneous gas absorption and dust removal.

A typical venturi scrubber is a flue with a constricted throat, as shown in Figure 6-7. Liquid is injected into the high-velocity gas stream either at the inlet to the converging section or at the venturi throat. The turbulent gas atomizes the liquid into fine droplets, which provide a large surface area for gas/liquid contact that permits the adsorption of contaminants. As the throat opens, the gas velocity decreases and water particles leave the gas stream.

Venturi scrubbers are used to remove gas stream particulates down to approximately 1 micron mean particle size.

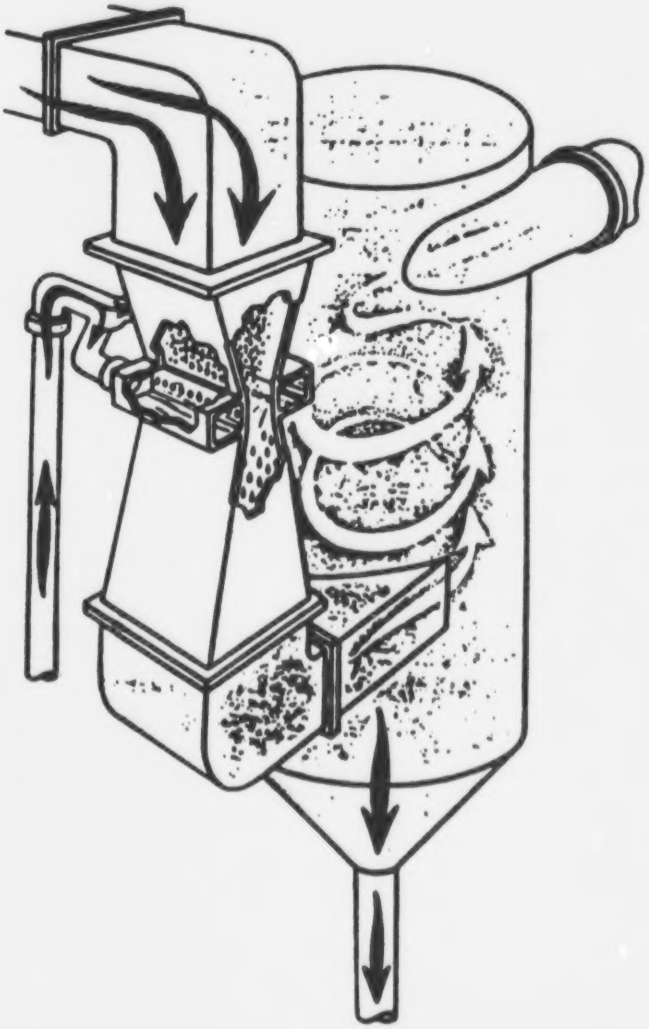


Figure 6-7
VENTURI SCRUBBER

Tray scrubbers are perforated plates with target baffles. The water level is maintained above a stack of two or three trays. The geometrical relationship of the tray thickness, the hole size and spacing, and the impinger details result in a high efficiency device for the removal of particles less than 2 microns in diameter. Normally, a venturi scrubber or an inertial separator is placed immediately in front of a tray scrubber.

A number of wet scrubbers employ a unique geometry that utilizes the gas flow to generate scrubbing action. These self-induced scrubbers are able to obtain relatively good particulate removal efficiency while using relatively low gas differential pressures. In a typical unit, as shown on Figure 6-8, the water level controls the scrubbing action of the gas. The higher the water level, the greater, or longer, the contact between the gas stream and the water particles.

6.2.2.5 Dry Scrubbing Systems

Dry scrubbers have been used in the electric power industry, specifically with coal-burning power plants, for a number of years. Recently, this technology has been adapted to control particulate and acid gas incinerator emissions. (It is included in this chapter because its operation is similar to that of a wet scrubber and water is often added to the gas stream, although not enough water to produce a condensate.) A particulate collection device (fabric filter or ESP) is required downstream of the dry scrubber.

The Framingham Refuse Reduction Facility in Massachusetts was the first incinerator in North America to utilize dry scrubbing. The system consists of two basic components: an Upflow Quench Reactor (Figure 6-9) and a Dry Scrubber

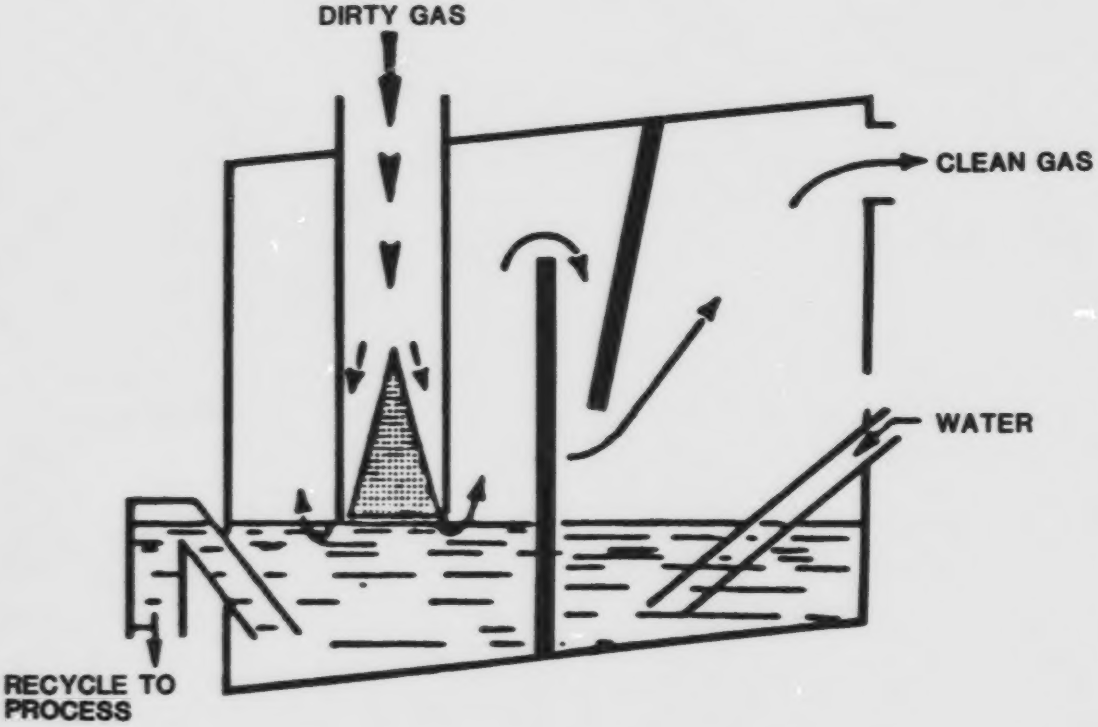

DIRTY GAS
CLEAN GAS
WATER
RECYCLE TO PROCESS

Figure 6-8
SELF-INDUCED SPRAY SCRUBBER

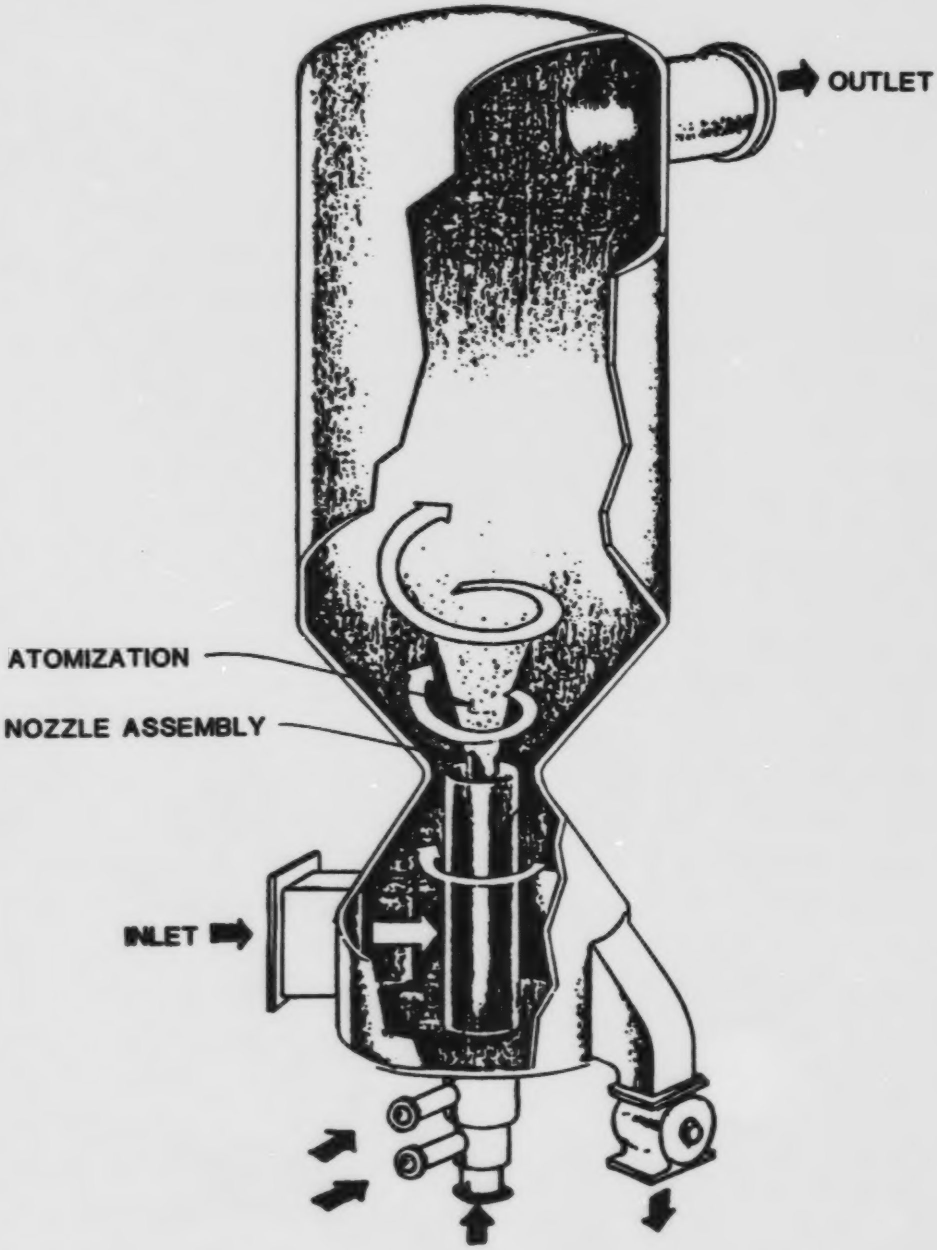

OUTLET
ATOMIZATION
NOZZLE ASSEMBLY
INLET

Figure 6-9
UPFLOW QUENCH REACTOR

(Figure 6-10). Systems are available from many manufacturers (Flakt, Niro, Teller, etc.) and have been applied to refuse and industrial incinerator systems in Europe and in North America.

In a typical system hot incinerator exhaust gas enters the inlet of the quench reactor, a cyclonic element where larger particles drop out of the stream by inertial forces. Rising through the reactor, an alkali solution is sprayed into the swirling gas stream and fully wets it. The alkali (a lime slurry or sodium carbonate solution) neutralizes the acid component of the gas and quenches any sparklers within the gas flow. The reactor is designed to promote neutralization of the acidic gaseous components by formation of an alkali mist within the reactor.

The neutralized gas stream leaves the quench reactor at its adiabatic temperature, normally from 65°C to 80°C (150°F to 180°F) and passes through the dry scrubber. A highly crystalline inert material, from 3- to 20-micron particle size, is injected into the gas stream through the venturi. Either talc or waste product fines from various manufacturing industries can be used. Other systems (dry/dry systems) inject dry lime into the gas stream and utilize the lime as a sorbant. The gas moisture content must be controlled to 17% or greater for these dry/dry systems to function properly.

Within the venturi, the generated turbulence will tend to complete the neutralization process. In addition, the injected powder will adsorb particulate matter within the gas stream and will also act as a catalyst in promoting agglomeration of particulate matter. Particles down to the sub-micron range have been found to agglomerate to particles of 10 microns and greater.

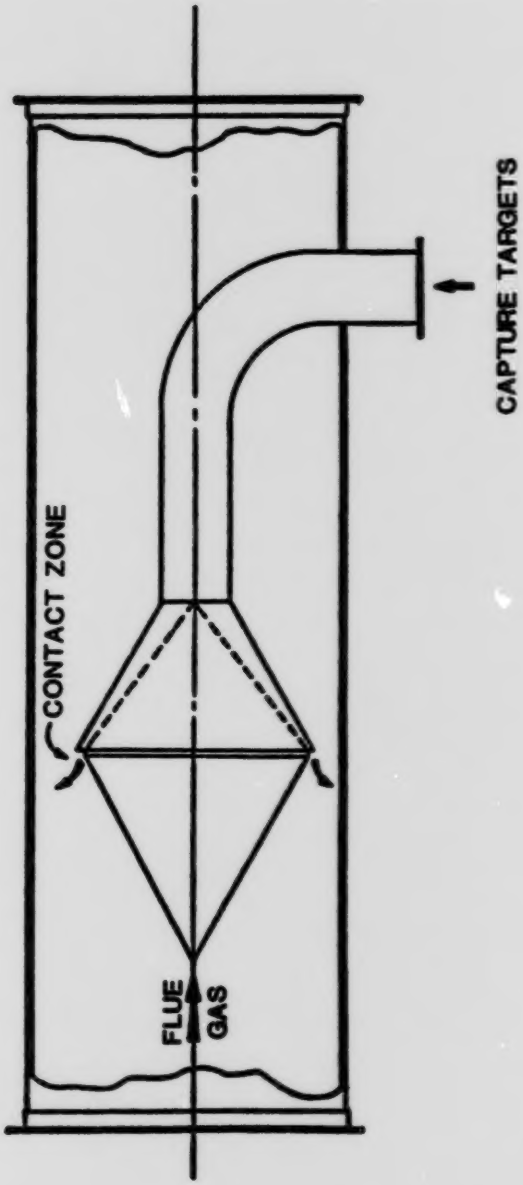

CAPTURE TARGETS
CONTACT ZONE
FLUE GAS

Figure 6-10
DRY SCRUBBER

A baghouse is placed downstream of the dry venturi to catch the particles in the gas stream; it removes 95 to 99% of the particulate matter exiting the incinerator. It is estimated that the use of an ESP in lieu of a baghouse would result in particulate removal efficiencies in excess of 90% with either dry lime or lime slurry injection into the gas stream.

6.2.2.6 Odour Control

Techniques for odour control for emissions from equipment, systems, and processes associated with incineration systems are normally one of the following:

- Fume incineration (afterburner)
- Packed tower (absorber)

Other techniques that have been used for incinerator odour control with varied records of success include the following:

- Catalytic oxidation
- Absorption
- Adsorption

These techniques are discussed below.

Burning is the ultimate odour control technique. Most odour-forming compounds are organic in composition. When oxidized or burned, they form carbon dioxide, water vapour, and other innocuous compounds, destroying the odour in the process. For most organic compounds, a temperature of 760°C (1400°F) maintained for a period of at least 0.5 seconds will be satisfactory for complete destruction. Complex organic molecules, such as phenols, require higher temperatures and retention times for effective destruction. In all cases, thermal destruction of any compound also requires effective mixing, or turbulence, within the furnace to ensure that the temperature/combustion requirements are met throughout the waste.

Separate fume incinerators are often used for odour destruction when other techniques are not effective, or when these odourous gases cannot be fed to the incinerator for destruction.

Fume incinerators (direct flame and catalytic units) are discussed in Chapter 4.

In absorption, the odourous constituent is absorbed into a solution by either chemical bond or solubility. In the case of solubility, an odourous gas may be absorbed by a liquid; however, if the odourous component of the gas does not condense and dissolve, the odourous gas may eventually be released.

Chemical absorption is generally an oxidative process. Many odours are unburned (unoxidized) hydrocarbons. By mixing or scrubbing with chemicals that have the ability to release oxygen (such as potassium permanganate, sodium hypochlorite, or chlorine dioxide), the odourous constituent can be effectively oxidized and lose its odour.

Packed towers, such as the one shown in Figure 6-11, are commonly used for the absorption process. Odorous gas enters the bottom of the tower and rises through a bed of packing. Liquid is injected at the top of the tower and the falling liquid wets the packing, providing effective contact and mixing between the odourous gas and the scrubbing liquid. The liquid, which contains the chemical oxidizer, can be collected at the base of the tower and recirculated back through the system.

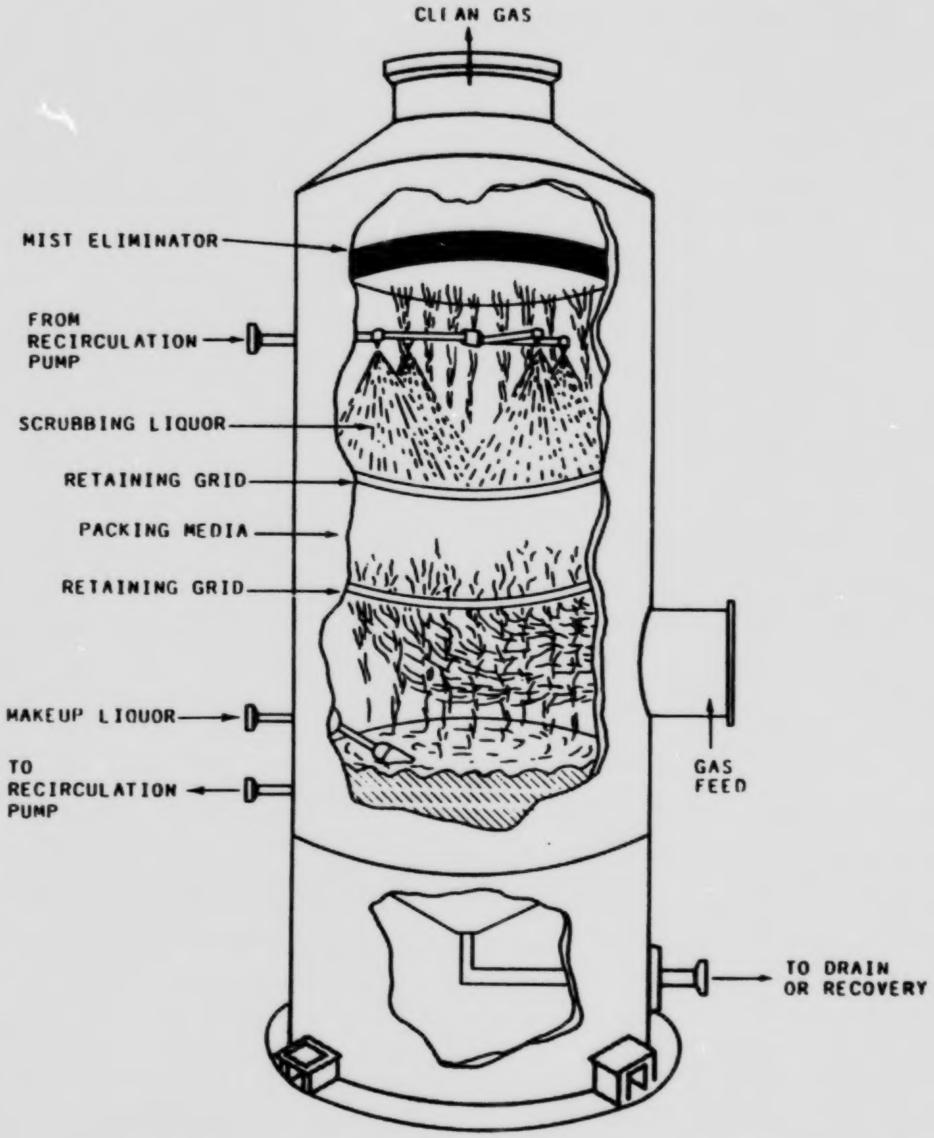

CLEAN GAS
MIST ELIMINATOR
FROM RECIRCULATION PUMP
SCRUBBING LIQUOR
RETAINING GRID
PACKING MEDIA
RETAINING GRID
MAKEUP LIQUOR
TO RECIRCULATION PUMP
GAS FEED
TO DRAIN OR RECOVERY

Figure 6-11
PACKED TOWER

These systems are relatively inexpensive from a capital investment standpoint. They also allow for the introduction of any scrubbing liquid or chemical. This feature is important because the choice of the proper chemical for odour destruction may require the use of a series of different compounds, eliminating ineffective ones until the chemical additive providing effective odour control is found.

Besides chemical oxidation, a number of odourous compounds can be altered, forming non-odourous compounds or forming other non-offensive odourous compounds by the addition of non-oxidative chemicals. One technique often used is the addition of caustic soda or a mild acid to scrubbing water. This changes the chemical nature of the odour, not necessarily oxidizing it, resulting in an acceptable discharge. Of course, the effectiveness of this procedure is a function of the nature of the odour, its constituent analysis, and its characteristics.

A number of materials have the physical property of high adsorptive capacity, i.e., the ability to adsorb or attract gases to their surfaces. Adsorptive media commonly used include activated carbon, silica gel, aluminum oxide, and magnesium silicate. The particles of each of these materials have extremely high surface area-to-weight ratios, providing high retentive capacity.

Activated carbon is the most widely used adsorbent. One reason for its popularity is that it has a low affinity for moisture. Moisture will not compete with contaminants in searching out the carbon surface. Other adsorbents will attract moisture and will have, therefore, a short useful life in wet-gas environments. Over a period of time, these other adsorbents can lose their effectiveness by picking up the moisture present as humidity in the air.

(Note that moisture particles present in a gaseous stream will reduce the effectiveness of a carbon filter to adsorb gaseous organic contaminants because of the physical blockage caused by the relatively large water particles.)

An important property of adsorbent materials is their ability to be regenerated. Normally, under the application of heat, the contaminant will be released and the adsorbent will be reactivated for reuse. Reactiviation may also require sparging of the spent adsorbent with steam to maximize its particulate surface area.

6.2.3 Selecting Appropriate Emissions Control Technology

Several important factors govern the selection of a system and equipment for controlling incinerator emissions, primarily regulatory requirements and utility availability; the nature of the waste stream, of course, must also be considered.

6.2.3.1 Regulatory Requirements

The first step in selecting an emissions control system is to examine the impacts of the relevant federal and provincial statutory requirements, as discussed in Chapter 2 including policies 01-01 and 01-03 which relate to combustion and air pollution control for refuse incinerators.

6.2.3.2 State-of-the-Art Control

The state-of-the-art control (SOAC) for incineration systems is a function of the nature of the waste stream and the type of incinerator used. SOAC is continually changing as new designs are developed and new equipment and processes become available. Examples of SOAC for selected equipment follow:

- For mass burn refuse incinerators SOAC appears to be a dry scrubber followed by a fabric filter.
- For industrial incinerators (rotary kiln application included) SOAC appears to be water quenching (including alkali) followed by a dry scrubbing system.
- SOAC for sewage sludge disposal in multiple hearth or fluid bed incinerators appears to be a venturi scrubber followed by an impingement tray scrubber.
- For controlled air incinerators burning paper waste, SOAC appears to be a fabric filter (baghouse).

In the United States and Europe dry scrubbing systems have been found to be SOAC for refuse incinerators. Table 6-3 lists selected standards and/or policy requirements for emissions based on Best Available Control Technology (BACT).

6.2.3.3 Utility Availability

A wet-control device uses a relatively large quantity of water for effective operation. If water is not available, a wet device cannot be used, regardless of other considerations.

In addition to a supply of water, wet-scrubbing systems require water at a low enough temperature for effective cooling of the gas stream. It is often desirable to reduce the temperature of the gas exiting the stack, and the use of relatively cool water may be necessary.

Table 6-3
Emission Standards Using BACT For Selected Locations

	CONNECTICUT	PENNSYLVANIA	NEW YORK	MICHIGAN	MASSACHUSETTS	CALIFORNIA	WEST GERMANY	SWEDEN	DENMARK
PARTICULATES	0.015 gr/dscf @ 12% CO_2	35 mg/Nm^3 (0.015 gr/dscf) @ 7% O_2	50 mg/Nm^3 (0.02 gr/dscf) @ 12% CO_2	35 mg/Nm^3 (0.015 gr/dscf) @ 12% CO_2	Best Available Control Tech. (BACT) required (default max. 60 mg/Nm^3 [0.03 gr/dscf])	0.01 gr/dscf @ 12% CO_2 (1)	50 mg/Nm^3 (0.02 gr/dscf) stricter "state" limits, e.g. 0.013 often apply.	Emission "goal" 20 mg/Nm^3 (0.01 gr/dscf) (2)	New "guideline" 40 mg/Nm^{2}3 (0.017 gr/dscf) (3)
HC1	90% reduction	90%	90% or 50 ppmv	90%	No statewide limit; specific limits for acid gases are set on a case by case basis in the permitting process. Dry scrubbers are required by BACT rule.	30 ppmv Use of wet or dry scrubbers is required.	50 mg/Nm^3	60 ppmv (100 mg/Nm^3) BACT required.	60 ppmv (100 mg/Nm^3)
SO_2	0.32 lb/10^6 Btu	None	"Acid Precip" New SO^2 limits see 6NYCRR 255-1	86 ppmv		30 ppmv	200 mg/Nm^3		30 mg/Nm^3 3
NO_x	0.6 lb/10^6 Btu	None	None	311 ppmv		(as NO_2) 140-200 ppmv	None		None
CO	CO/CO_2 ratio of 0.002	100 ppmv as 4-day avg.	"combustion index" of 99.5% (1)	113 ppmv as 24-hr. avg.	BACT	400 ppmv	100 mg/Nm^3	None	None
DIOXINS measured as 2,3,7,8-TCDD	No Limit	No Limit	No Limit	Total PCDD 0.52 µg/Nm^3 PCDF 0.5 µg/Nm^3 (over 3 hr.avg)	No Limit (2)	No Limit	No Limit	Existing plants 0.5-2.0 ng/Nm^3 New plants: 0.1 ng/Nm^3	All facilities: 1.0 ng/Nm^3

1. The combustion index (CI) is defined as follows with CO and CO_2 as carbon monoxide and carbon dioxide concentration in the exhaust: $CI = \frac{CO_2 \times 100}{CO2 + CO}$
2. Massachusetts enforces the following ambient standards for dioxin: 2.2 pg/m^3 gaseous, 1.1 pg/m^3 particulate.

A conventional electrostatic precipitator will not need a supply of water for operation, but a wet ESP will have a liquid discharge that must be cleaned prior to disposal. The sewerage requirement may be a limitation on system selection. If a discharge cannot be fed directly to an existing sewer, the cost of treating it may be prohibitive.

6.2.3.4 Predicting Performance

The collection efficiency of a control device is specific to the particular equipment in question, and usually varies from one manufacturer to another. Listed data on system efficiencies can be used to obtain a reasonable estimate of system performance and can be useful in system selection.

Table 6-4 compares the average removal efficiencies for individual gaseous contaminants of various types of control equipment. The relatively high removal of HCl is a function of the water circulated within the indicated device and the gas-to-water contact efficiency.

Table 6-5 lists average particulate removal efficiencies of control equipment as a function of particle size. Below one micron, which is not included within these data, removal efficiency of all but the electrostatic precipitator will show a substantial decrease.

Table 6-4
Average Removal Efficiencies of Air Pollution Control Systems
(Percent)

System Type	Particulate Mineral	Particulate Combustible	Hydrogen Chloride	Volatile Metals
None (settling chamber)	20	2	0	2
Dry Expansion Chamber	20	2	0	0
Spray Chamber	40	5	40	5
Wetted Wall Chamber	35	7	40	7
Wetted Close-Space Baffles	50	10	50	10
Mechanical Cyclone (dry)	70	30	0	0
Medium Energy Wet Scrubber	90	80	95	80
Electrostatic Precipitator	99	90	0	90
Fabric Filter	99.9	99	0	99

NOTES:

1. Removal efficiencies for carbon monoxide and hydrocarbons are zero for the above systems.
2. Combustible particulate and volatile metals are assumed to be primarily < 5μ mean diameter.

SOURCE: K. Akita, Journal of Polymer Science, Volume 5, Page 833.

Table 6-5
Average Particulate Removal Efficiencies of Gas Cleaning Equipment

Equipment Type	Collection and Removal Efficiency 50μ	5μ	1μ
Inertial Collector	95	16	3
Medium Efficiency Cyclone	94	27	8
High Efficiency Cyclone	96	73	27
Impingement Scrubber	98	83	38
Electrostatic Precipitator	>99	99	86
Wet Electrostatic Precipitator	>99	98	92
Flooded Disc Scrubber, Low Energy	100	99	96
Flooded Disc Scrubber, Medium Energy	100	99	97
Venturi Scrubber, Medium Energy	100	>99	97
Venturi Scrubber, High Energy	100	>99	98
Shaker Type Fabric Filter	>99	>99	99
Reverse Jet Fabric Filter	100	>99	99

SOURCE: J. Starimand, Chemical Engineering (London), Volume 194, Page 310

It is usually not possible to obtain data on particle size distribution without performing extensive tests on the equipment in question burning the fuel (waste) in question.

If this information were available, selecting a control system would be a simple exercise of matching particle size input to the known incinerator particulate removal efficiency.

Normally, the actual selection of a control system and system operating parameters requires an "educated guess" on the part of the engineer and the manufacturer because the precise particle size distribution is not known. Tables 6-6 and 6-7 list particle size distribution for tests on two incinerators, one burning sewage sludge and the other firing refuse.

Table 6-6
Sewage Sludge Incineration Airborne Particle Size

	% By Weight Less Than Indicated Size	
	Location a	Location b
Particulate Loading		
g/dry m^3	4.30	0.02
kg/h	98.48	0.67
g/wet kg	23.25	0.16
Size Distribution, microns		
18.7	37.9	100.0
11.7	30.6	98.0
8.0	16.4	94.9
5.4	6.6	93.4
3.5	2.6	92.8
1.8	1.6	83.3
1.1	0.9	67.7
0.76	0.1	54.6

(a) Measured at incinerator outlet, without controls, burning 102 tonnes/day wet sludge cake

(b) Measured after venturi scrubber with a total pressure drop of 7.47 kPa

SOURCE: C.R. Brunner, INCINERATION SYSTEMS: Selection and Design, Van Nostrand Reinhold, 1984

Table 6-7
Refuse Incineration (Waterwall) Airborne Particle Size

	Unit	
	255 tonnes/day	122 tonnes/day
Particle Specific Gravity, kg/m^3	43.25	60.39
Particle Bulk Density, kg/m^3	494.97	150.57
Loss on Ignition @ 760°C	8.20	30.40
Size Distribution, % By Weight Less Than Indicated Size: Microns		
30	40.4	50.0
20	34.6	45.0
15	31.1	42.1
10	26.8	38.1
8	24.8	36.3
6	22.3	33.7
4	19.2	30.0
2	14.6	23.5
Particulate Emission Rate:		
g/kg	10.98	4.06
kg/h	116.50	20.68

NOTE: Measurements made at incinerator exit, prior to any control equipment.

SOURCE: C.R. Brunner, INCINERATION SYSTEMS: Selection and Design, Van Nostrand Reinhold, 1984.

6.2.3.5 Selection

As noted above, many factors are to be considered in selecting the appropriate control device. The nature of the waste stream is a factor, as well as the type of incinerator equipment that is used. In addition, regulatory constraints must be considered.

6.2.4 Air Toxics Removal

Incinerator systems which meet the requirements of Policy 01-01 and 01-03 will minimize the formation of organics including toxic chlorinated compounds, and minimize their emission into the ambient air. Control systems which achieve the requirements of this policy will also reduce the emissions of metals (including beryllium, arsenic, cadmium chromium, mercury, nickel, lead, selenium, antimony and zinc) and metallic compounds.

6.3 SOLID WASTE

6.3.1 Solid Residues

6.3.1.1 Quantities/Characteristics

Ash produced from incineration is primarily inorganic and can be classified into the categories of fly ash and bottom ash. Fly ash is entrained in exhaust gases leaving the incinerator and is usually captured in air pollution control equipment. Bottom ash is that portion that remains in the combustion chamber after incineration and is normally associated with inerts.

Ash composition varies greatly and depends on the composition of the waste being incinerated. In municipal refuse incineration, solid materials not susceptible to oxidation (i.e., ceramic or glass) constitute most of the ash; however, depending on the type of incinerator and its efficiency, the ash might also contain unburned waste feed.

The relative proportion of fly ash to bottom ash depends on the waste composition and on the incinerator design and operation. When liquid or gaseous wastes are incinerated, no bottom ash and relatively little fly ash result. However, more ash is produced by liquids derived from complex chemical processes containing inerts or from blending procedures that create incompatible reactions which produce inerts.

When solid wastes are incinerated, both bottom ash and fly ash result. The bottom ash from incineration of sewage sludge is approximately from 15 to 20% of the total mass feed. Refuse incineration can produce ash in varying amounts depending on the waste material burned, but ash content normally ranges from 5 to 15% of the total mass feed.

The bottom ash contains primarily inorganic and carbonaceous compounds. Usually less than 3% of the total weight of carbonaceous compounds is made up of trace compounds, including heavy metals.

6.3.1.2 Wet and Dry Solids

Ash can be removed by either wet or dry methods. Fly ash, along with other gaseous pollutants, should be removed by an air pollution control system. If a wet system is used, fly ash and gases will form a sludge if allowed to concentrate in the scrubber. Normally, however, scrubber blowdown will control the solids so that sludges do not form. Again, the composition of the scrubber wastewater stream depends directly on the wastes being incinerated. Blowdown is usually mixed with other liquid waste streams for further treatment and disposal.

If a baghouse or an electrostatic precipitator are used to remove fly ash, a dry solid residue results.

6.3.2 Solid Waste Handling

6.3.2.1 Dry Versus Wet Handling

Bottom ash is discharged continuously or periodically. In a continuous system, the ash discharges into a dry ash bin or wet well. From this point, it is transferred to a container or truck, usually by means of drag conveyors. Lighter ash is collected at the outlet of the incinerator and is normally directed into a closed system.

Classification of the ash residues as hazardous or nonhazardous should be determined using the leachate extraction procedure in Regulation 309.

Fly ash collected in a wet scrubber leaves the system with the scrubber blowdown and is further treated in a liquid waste treatment system.

Figure 6-12 is a schematic of a solid waste incineration process including bottom ash collection and fly ash scrubbing system.

6.3.2.2 Sludge Dewatering

Incineration operations may generate sludge from water/wastewater treatment and ash sludge if a wet ash removal system is employed. Sludges are normally dewatered to reduce the volume before landfilling. Sludge dewatering is usually accomplished by gravity.

6.4 LIQUID WASTES

6.4.1 Wastewater Sources

Figure 6.12 shows an incineration process with emissions treatment and disposal options.

6.4.1.1 Wet Scrubbers

Gaseous pollutants and particulates resulting from incineration can be captured by one of the following wet methods: (1) water in a quench tower, (2) water in a scrubber, or (3) alkaline liquid in a scrubber. The wet bottom quench tower, used mainly to lower the flue gas temperature, also functions as a scrubber by removing a small amount of particulate and gaseous pollutants from the incinerator exhaust. Water scrubbers are used for capturing the majority of gaseous pollutants in the combustion gas prior to atmospheric discharge. An alkaline scrubber is used to further reduce gaseous components that were not removed in the quench tower or water scrubber.

A water quench tower is used when a waste heat recovery system is not part of the incinerator design package. In addition to lowering the flue gas temperature, it operates like a single-pass scrubber. The quench tower effluent characteristics are highly variable, depending on incinerator operation, waste material being incinerated, quench tower feed rates, and scrubbing efficiency of the tower.

A wet scrubber with water as a medium is normally used downstream of the waste heat recovery system or water quench tower. Water scrubber effluents are quite different from quench tower effluents. Normally, scrubbers are recirculated systems with blowdown that controls the amount of total dissolved solids (TDS). The blowdown rate is variable, depending the water feed rate and on the

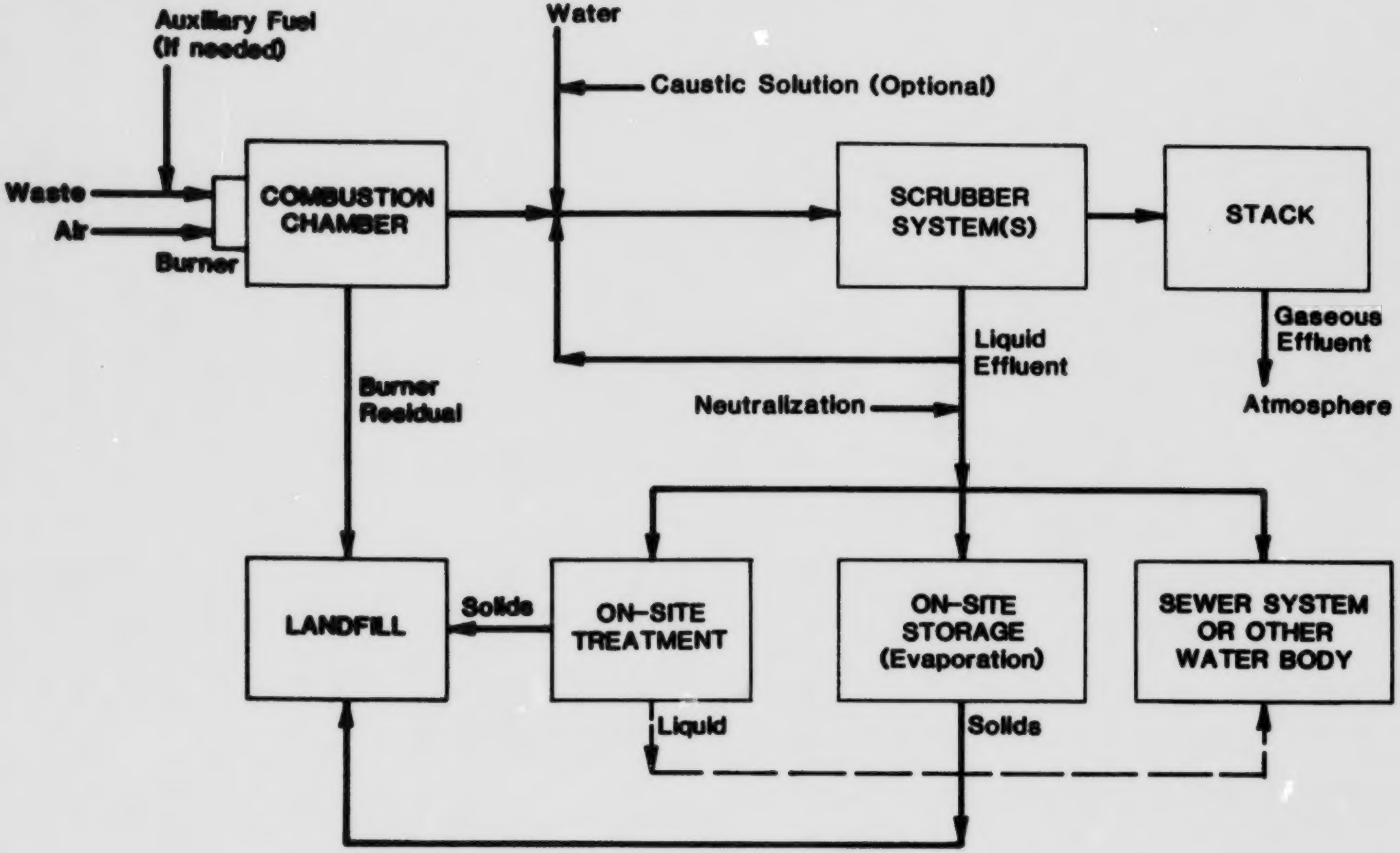

Auxiliary Fuel (If needed)
Waste
Air
Burner
COMBUSTION CHAMBER
Water
Caustic Solution (Optional)
SCRUBBER SYSTEM(S)
STACK
Gaseous Effluent
Atmosphere
Liquid Effluent
Neutralization
Burner Residual
LANDFILL
Solids
ON-SITE TREATMENT
ON-SITE STORAGE (Evaporation)
SEWER SYSTEM OR OTHER WATER BODY
Liquid
Solids

Figure 6-12

INCINERATION PROCESS WITH EMISSIONS TREATMENT AND DISPOSAL OPTIONS

6

amount of acidic gases in the incinerated waste stream. Generally, blowdown occurs when the TDS content reaches approximately 3%. Water scrubber effluents are usually acidic in nature and may contain trace quantities of incinerated waste constituents and/or organics. Acidic effluents may be further processed for acid recovery or may be treated as a liquid waste. As a waste liquid, the stream may or may not be neutralized prior to mixing with other waste streams.

Alkaline (caustic) scrubbers are often used in conjunction with quench towers and/or water scrubbers. This type of scrubber would be used to remove acidic gases and other residual combustion products not captured in the water scrubbers. Alkaline scrubbers are usually recirculated systems with blowdown. Scrubber effluents are generally alkaline since the scrubbing medium is used in excess to ensure that all noxious substances in the exhaust gas are removed prior to being discharged to the atmosphere. Alkaline scrubber effluents may or may not be neutralized prior to mixing with other liquid waste streams.

6.4.1.2 Other Wastewater Sources

Other wastewater sources include waste heat recovery boiler blowdown, raw water treatment wastewaters, cooling tower blowdown, sludge dewatering liquid wastes, site runoff, and drainage from waste storage areas. All of these wastewaters are typically rich in suspended and dissolved solids and are of similar chemical makeup. Some streams may contain hazardous compounds and/or organics. Depending on the overall wastewater treatment program, it may be desirable to (1) separate some streams from the total combination of streams in order to treat them separately prior to disposal or (2) combine them with other wastewater streams.

Chapter 7
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Appendix A

GLOSSARY

Abatement: The reduction in degree or intensity of pollution.

Abrasion: The wearing away of surface material by the scouring action of moving solids, liquids, or gases.

Absorption: The penetration of one substance into or through another.

Acute Toxicity: Any poisonous effect produced within a short period of time, usually up to 24-96 hours, resulting in severe biological harm and often death.

Aerosol: A particle of solid or liquid matter that can remain suspended in the air because of its small size.

Afterburner: A device that includes an auxiliary fuel burner and combustion chamber to incinerate combustible gas contaminants.

Air Classifier: A system that uses a forced air stream to separate mixed material according to size, density, and aerodynamic drag of the pieces.

Air Cooled Wall: A refractory wall with a lane directly behind it through which cool air flows.

Air Emissions: For stationary sources, the release or discharge of a pollutant by an owner or operator into the ambient air either by means of a stack or as a fugitive dust, mist, or vapour as a result inherent to the manufacturing or forming process.

Air Heater: A heat exchanger through which air passes and is heated by a medium of a higher temperature, such as hot combustion gases in metal tubes.

Air Pollutant: Dust, fumes, smoke, and other particulate matter, vapour, gas, odourous substances, or any combination thereof.

Air Pollution: The presence of any air pollutant in sufficient quantities as to interfere with the enjoyment of life or property.

Ambient Air: That portion of the atmosphere external to buildings to which the general public has access.

Ash: Inorganic residue remaining after ignition of combustible substances determined by definite prescribed methods.

Autogenous (Autothermic) Combustion: The burning of a wet organic material where the moisture content is at such a level that the heat of combustion of the organic material is sufficient to vapourize the water and maintain combustion; no auxiliary fuel is required except for startup of the process.

Background Level: With respect to air pollution, amounts of pollutants present in the ambient air due to natural sources.

Baffles: Deflector vanes, guides, grids, grating, or similar devices constructed or placed in air or gas flow systems, flowing water, or slurry systems to effect a more uniform distribution of velocities, absorb energy, divert, guide, or agitate fluids, and check eddies.

Baghouse: An air pollution abatement device used to trap particulates by filtering gas streams through large fabric bags usually made of cloth or glass fibers.

Barometric Damper: A hinged or pivoted plate that automatically regulates the amount of air entering a duct, breeching, flue connection, or stack, thereby maintaining a constant draft within an incinerator.

Batch-Fed Incinerator: An incinerator that is periodically charged with waste; one charge is allowed to burn out before another is added.

Battery Wall: A double or common wall between two incinerator combustion chambers; both faces are exposed to heat.

Blowdown: The minimum discharge of recirculating water for the purpose of discharging materials contained in the process, the further buildup of which would cause concentrations or amounts exceeding limits established by best engineering practice.

Blower: A fan used to force air or gas under pressure.

Bottom Ash: The solid material that remains on a hearth or falls of the grate after thermal processing is complete.

Breeching: A passage that conducts the products of combustion to a stack or chimney.

Bridge Wall: A partition between chambers over which the products of combustion pass.

British Thermal Unit (Btu): The amount of heat required to raise the temperature of one pound of water one degree Farenheit.

Bulky Waste: Large items of refuse, including but not limited to appliances, furniture, large auto parts, trees, branches, and stumps which cannot be handled by normal solid waste processing, collection, or disposal methods.

Bunker "C" Oil: A general term used to indicate a heavy viscous fuel oil.

Burning Area: The horizontal projection of a grate, a hearth, or both.

Burning Hearth: A solid surface to support the solid fuel or solid waste in a furnace and upon which materials are placed for combustion.

Burning Rate: The volume of solid waste incinerated or the amount of heat released during incineration. The burning rate is usually expressed in pounds of solid waste per square foot of burning area per area or in British Thermal Units per cubic foot of furnace volume per hour.

Butterfly Damper: A plate or blade installed in a duct, breeching, flue connection, or stack that rotates on an axis to regulate the flow of gases.

Carbonaceous Matter: Pure carbon or carbon compounds present in the fuel or residue of a combustion process.

Catalytic Combustion System: A process in which a substance is introduced into an exhaust gas stream to burn or oxidize vapourized hydrocarbons or odourous contaminants; the substance itself remains intact.

Centrifugal Collector: A mechanical system using centrifugal force to remove aerosols from a gas stream or to dewater sludge.

Chain Grate Stoker: A stoker with a moving chain as a grate surface. The grate consists of links mounted on rods to form a continuous surface that is generally driven by a shaft with sprockets.

Chamber: An enclosed space inside an incinerator.

Charge: The amount of solid waste introduced into a furnace at one time.

Charging Chute: An overhead passage through which waste materials drop into an incinerator.

Charging Gate: A horizontal, movable cover that closes the opening on a top-charging furnace.

Charging Hopper: An enlarged opening at the top of a charging chute.

Checker Work: A pattern of multiple openings through which the products of combustion pass to accelerate the turbulent mixing of gases.

Clamshell Bucket: A vessel used to hoist and convey materials; it has two jaws that clamp together when it is lifted by specially attached cables.

Classification: The separation and rearrangement of waste materials according to composition (e.g., organic or inorganic), size, weight, colour, shape, and the like, using specialized equipment.

Clinkers: Hard, sintered, or fused pieces of residue formed in a furnace by the agglomeration of ash, metals, glass, and ceramics.

Codisposal: The technique in which sludge is combined with other combustible materials (e.g., refuse, refuse-derived fuel, coal) to form a furnace feed with a higher heating value than the original sludge.

Cold Drying Hearth: A surface upon which unheated waste materials are placed to dry or to burn. Hot combustion gases are then passed over the materials.

Combustibles: Materials that can be ignited at a specific temperature in the presence of air to release heat energy.

Combustion: The production of heat and light energy through a chemical process, usually oxidation.

Combustion Gases: The mixture of gases and vapours produced by burning.

Commercial Waste: All types of solid wastes generated by stores, offices, restaurants, warehouses, and other nonmanufacturing activities, excluding residential and industrial wastes.

Conduction: The transfer of heat by physical contact between substances.

Construction and Demolition Waste: Rubble resulting from construction, remodeling, repair, and demolition operations on houses, commercial buildings and other structures, and pavements.

Container: Any portable enclosure in which a material can be stored, handled, or transported.

Contaminant: Any physical, chemical, biological, or radiological substance in water.

Continuous Feed Incinerator: An incinerator into which solid waste is charged almost continuously to maintain a steady rate of burning.

Controlled-Air Incinerator: An incinerator with two or more combustion chambers in which the amounts and distribution of air are controlled. Partial combustion takes place in the first zone and gases are burned in a subsequent zone or zones, of pyrollysis.

Corrosion: The gradual wearing away of a substance by chemical action.

Cover Material: Soil or other suitable material that is used to cover wastes daily or periodically in a properly operated sanitary or secure landfill.

Curtain Wall: A refractory construction or baffle that deflects combustion gases downward.

Cyclone Separator: A separator that uses a swirling air flow to sort mixed materials according to the size, weight, and density of the pieces.

Dispersion Technique: The use of dilution to attain ambient air quality levels, including any intermittent or supplemental control of air pollutants varying with atmospheric conditions.

Disposal: The planned release or placement of waste in a manner that precludes recovery.

Disposal Facility: A collection of equipment and associated land area which serves to receive waste and dispose of it. The facility may have available one, many, or all of a large number of disposal methods.

Dissolved Solids: The anhydrous residues of the dissolved constituents in water.

Downpass: A chamber or gas passage placed between two combustion chambers to carry the products of combustion downward.

Draft: The difference between the pressure within an incinerator and that in the atmosphere.

Drag Conveyor: A conveyor that uses vertical steel plates fastened between two continuous chains to drag material across a smooth surface.

Drop Arch: A form of construction that supports a vertical refractory furnace wall and serves to deflect gases downward.

Drying Hearth: A solid surface in an incinerator upon which wet waste materials, liquids, or waste matter that may turn to liquid before burning are placed to dry or to burn with the help of hot combustion gases.

Duct: A conduit, usually metal or fiberglass, round or rectangular in cross section, used for conveyance of air.

Dust: Fine grain particles light enough to be suspended in the air.

Effluent: Waste materials, usually waterborne, discharge into the environment, treated or untreated.

Electrostatic Precipitator (ESP): An air pollution control device that imparts an electric charge to particles in a gas stream causing them to collect on an electrode.

Emission Rate: The amount of pollutant emitted per unit of time.

Exhaust System: The system comprised of a combination of components which provides for enclosed flow of exhaust gas from the furnace exhaust port to the atmosphere.

Explosive Wastes: Wastes which are unstable and may readily undergo violent chemical change or explode. Such wastes may react violently on contact with air or water, or form explosive mixtures, or generate toxic fumes when mixed with water.

Filter: A porous device through which a gas or liquid is passed to remove suspended particles or dust.

Filtration: A physical removal of solid particles from an aqueous waste stream by using a filter medium.

Final Cover: Cover material that is applied upon closure of a landfill and that is permanently exposed to the surface.

Fire Point: The lowest temperature at which an oil vapourizes readily enough to burn at least five seconds after ignition.

Firebrick: Refractory brick made from fireclay.

Fireclay: A sedimentary clay containing only small amounts of fluxing impurities, high in hydrous aluminum silicate, and capable of withstanding high temperatures.

Fixed Carbon: The ash-free carbonaceous material that remains after volatile matter is driven off a dry solid waste sample.

Fixed Grate: A grate without moving parts, also called a stationary grate.

Flash Drying: The process of drying a wet organic material by passing through a high temperature zone at such a rate that the water is rapidly evaporated but the organic material, protected by the boiling point of water, is not overheated.

Flash Point: The minimum temperature at which a liquid or solid gives off sufficient vapour to form an ignitable vapour-air mixture near the surface of the liquid or solid.

Flue: Any passage designed to carry combustion gases and entrained particulates.

Flue Gas: The products of combustion, including pollutants, emitted to the air after a production process or combustion takes place.

Flue Gas Desulphurization: The operation of removing sulphur oxides from exhaust gas streams of a combustion process.

Flue-Fed Incinerator: An incinerator that is charged through a shaft that functions as a chute for charging waste and as a flue for carrying the products of combustion.

Fluidized Bed Combustion: Oxidation of combustible material within a bed of solid, inert (noncombustible) particles which under the action of vertical hot air flow will act as a fluid.

Fly Ash: The airborne combustion residue from burning fuel.

Forced Draft: The positive pressure created by the action of a fan or blower which supplies the primary or secondary combustion air in an incinerator.

Fossil Fuel: Natural gas, petroleum, coal, and any form of solid, liquid, or gaseous fuel derived from such materials for the purpose of creating useful heat.

Fouling: The impedance to the flow of fluids or heat that results when material accumulates in flow passages or on heat absorbing surfaces in an incinerator or other combustion chamber.

Fuel: Any material which is capable of releasing energy or power by combustion or other chemical or physical means.

Fugitive Emissions: Emissions other than those from stacks or vents.

Fume: Solid particles under one micron in diameter formed as vapours condense or as chemical reactions take place.

Furnace: A combustion chamber; an enclosed structure in which heat is produced.

Furnace Arch: A nearly horizontal structure that extends into a furnace and serves to deflect gases.

Fusion Point: The temperature at which a particular complex mixture of minerals can flow under the weight of its own mass.

Grate: A piece of furnace equipment used to support solid waste or solid fuel during the drying, igniting, and burning process.

Groundwater: A body of water, generally within the boundaries of a watershed, which exists in the internal passageways of porous geological formations (aquifers) and which flows with gravity.

Guillotine Damper: An adjustable plate, used to regulate the flow of gases, installed vertically in a breeching.

Hazardous Waste Leachate: The liquid that has percolated through or drained from hazardous waste emplaced in or on the ground.

Hazardous Waste Management: The systematic control of the collection, source separation, storage, transportation, processing, treatment, recovery, and disposal of hazardous wastes.

Hearth: The bottom of a furnace on which waste materials are exposed to the flame.

Heat Balance: An accounting of the distribution of the heat input and output of an incinerator or boiler, usually on an hourly basis.

Hot Drying Hearth: A surface upon which waste materials are placed to dry or to burn. Hot combustion gases first pass over the materials and then under the hearth.

Ignition Arch: A refractory furnace arch or surface located over a fuel bed to radiate heat and to accelerate ignition.

Ignition Temperature: The lowest temperature of a fuel at which combustion becomes self-sustaining.

Impoundment: The restraint of a flowable material behind a structural barrier, such as a dam, levee, dike, or pond.

Incineration: An engineered process using controlled flame combustion to thermally degrade waste materials.

Incinerator Stoker: A mechanically operable moving grate arrangement for supporting, burning, or transporting solid waste in a furnace and discharging the residue.

Induced Draft: The negative pressure created by the action of a fan, blower, or other gas-moving device located between an incinerator and a stack.

Infiltration Air: Air that leaks into the chambers or ducts of an incinerator.

Inorganic Matter: Chemical substances of mineral origin, not containing carbon-to-carbon bonding.

Insulated Wall: A furnace wall on which refractory material is installed over insulation.

Isokinetic Sampling: Sampling in which the linear velocity of the gas entering the sampling nozzle is equal to that of the undisturbed gas stream at the sample point.

Kraft Paper: A comparatively coarse paper noted for its strength and used primarily as a wrapper or packaging material.

Lagoon: Any pond for the temporary or permanent storage of liquid.

Landfill: A land disposal site employing an engineered method of disposing of wastes on land in a manner that minimizes environmental hazards by spreading wastes in thin layers, compacting the wastes to the smallest practical volume, and applying cover materials at the end of each operating day.

Leachate: The fluid stream which issues from a pile or cell of solid materials and which contains water, dissolved solids, and decomposition products of the solids.

Liner: The material used on the inside of a furnace wall to ensure that a chamber is impervious to escaping gases; the material used on the inside of a sanitary landfill to ensure that the basin is impervious to fluids.

Macroencapsulation: The isolation of a waste by embedding it in or surrounding it with a material which acts as a barrier to water or air.

Magnetic Separation: The process by which a permanent magnet or electromagnet is used to attract magnetic materials away from mixed waste.

Masking: Blocking out one sight, sound, or smell with another.

Microencapsulation: The isolation of a waste from external effects by mixing it with a material which then cures or converts it to a solid, nonleaching barrier.

Mist: Liquid particles, measuring 40-500 microns in diameter, that are formed by condensation of vapour.

Mixing Chamber: A chamber usually placed between the primary and secondary combustion chambers and in which the products of combustion are thoroughly mixed by turbulence that is created by increased velocities of gases, checkerwork, or turns in the direction of the gas flow.

Modular Combustion Unit: One of a series of incinerator units designed to operate independently and can handle small quantities of solid waste.

Monolithic: Describing a structure which is without cracks or seams, self-supporting, and essentially homogeneous.

Movable Grate: A grate with moving parts.

Multiple Chamber Incinerator: An incinerator that consists of two or more chambers, arranged as in-line or retort types, interconnected by gas passage parts or flues.

Mutagenic: The property of a substance or mixture of substances which, when it interacts with a living organism, causes the genetic characteristics of the organism to change and its offspring to have a decreased life expectancy.

Natural Draft: The negative pressure created by the height of a stack or chimney and the difference in temperature between flue gases and the atmosphere.

Nonleaching: Generally applied to a landfill structure or material, describing some material which will not permit water to enter or fluids to leave.

One-Hundred Year Flood: The flood that has a 1% or 1 in 100 chance of recurring in any year, or a flood of magnitude equalled or exceeded once in 100 years on the average over a significantly long period.

Opacity: Degree of obscuration of light; for example, a window has zero opacity while a wall has 100% opacity.

Open Burning: The combustions of any material without: (a) control of combustion air to maintain adequate temperature for efficient combustion, (b) containment of the combustion-reaction in an enclosed device to provide sufficient residence time and mixing for complete combustion, or (c) emission of the combustion products through a stack or vent adequate for both visual monitoring and point source sampling.

Open Hearth Furnace: A long, wide, shallow reverberatory furnace used to produce steel from cast or pig iron.

Open Pit Incinerator: A burning apparatus that has an open top and a system of closely spaced nozzles that place a stream of high velocity air over the burning zone.

Organic Matter: Chemical substances comprised mainly of carbon covalently bonded. May have its origin in animal or plant life, coal, petroleum, or laboratory synthesis.

Orsat: An apparatus used to analyze flue gases volumetrically by dissolving the constituent gases selectively in various solvents.

Oscillating-Grate Stoker: A stoker whose entire grate surface oscillates to move the solid waste and residue over the grate surface.

Overfire Air: Air under control as to quantity and direction, introduced above and beyond a fuel bed by induced or forced draft.

Packed Tower: A pollution control device that forces dirty gas through a tower packed with crushed rock, wood chips, or other packing while liquid is sprayed over the packing material. Pollutants in the gas stream either dissolve in or chemically react with the liquid.

Particulate Matter: Any material, except water in uncombined form, that is or has been airborne and exists as a liquid or a solid at standard conditions.

Particulates: Fine liquid or solid particles, such as dust, smoke, mist, fumes, or smog, found in the air or in emissions.

Pitot Tube: A device for measuring the velocity of flowing fluid by using the velocity head of the stream as an index velocity.

Plume: Visible emissions from a flue or chimney.

Polychlorinated Biphenyls (PCBs): A series of hazardous compounds which have been manufactured for over 40 years for such common uses as electrical insulation and heating/cooling equipment.

Polynuclear Aromatics: A class of organic materials with characteristic multiple ring molecular structure which is suspected of causing genetic damage.

Polyvinyl Chloride (PVC): A common plastic material that releases hydrochloric acid when burned.

Pour Point: The lowest temperature at which an oil will flow or can be poured under specified conditions of test.

Precipitators: Air pollution control devices that collect particles from an emission by mechanical or electrical means.

Primary Combustion Air: The air admitted to a combustion system when the fuel is first oxidized.

Primary Pollutant: A pollutant emitted directly from a polluting stack.

Process Waste: Any designated toxic pollutant which is inherent to or unavoidable resulting from any manufacturing process, including that which comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product.

Pyrolysis: The chemical decomposition of organic matter through the application of heat in an oxygen deficient atmosphere.

Quench Tank: A water-filled tank used to cool incinerator residues or hot materials during industrial processes.

Rated Incinerator Capacity: The number of tons of solid waste that can be processed in an incinerator per 24-hour period when specified criteria prevail.

Reciprocating Grate Stoker: A stoker with a bed of bars or plates arranged so that alternate pieces, or rows of pieces, reciprocate slowly in a horizontal sliding mode and act to push the solid waste along the stoker surface.

Recoverable Resources: Materials that still have useful chemical or physical properties after serving a specific purposes and can, therefore, be reused or recycled for the same or other purpose.

Recycled Material: A material that is used in place of a primary, raw, or virgin material in manufacturing a product and consists of materials derived from post consumer waste, industrial scrap, and material derived from agricultural wastes and other items, all of which can be used in the manufacture of new products.

Refractory Material: Nonmetallic substances used to line furnaces because they can endure high temperatures and resist abrasion, spalling, and slagging.

Refractory Wall: A wall made of heat resistant material.

Refuse-Derived Fuel (RDF): The combustible, or organic, portion of municipal waste that has been separated out and processed for use as fuel.

Residual Oil: A general term used to indicate a heavy viscous fuel oil.

Residue: Solid or semisolid materials such as, but not limited to, ash, ceramics, glass, metal, and organic structures remaining after incineration or processing.

Residue Conveyor: Generally a drag or flight conveyor used to remove incinerator residue from a quench through to a discharge point.

Retort-Type Incinerator: A multiple chamber incinerator in which the gases travel from the end of the ignition chamber, then pass through the mixing and combustion chambers.

Reverberatory Furnace: A furnace in which the fuel is not in direct contact with the charge (waste) but the heating effect is basically generated by reflection down from a refractory roof.

Rocking-Grate Stoker: A stoker with a bed of bars or plates on axles; when the axles are rocked in a coordinated manner, the solid waste is lifted and advanced along the surface of the grate.

Rotary Kiln Stoker: A cylindrical, inclined device that rotates, thus causing the solid waste to move in a slow cascading and forward motion.

Sanitary Landfill Liner: An impermeable barrier, manufactured, constructed, or existing in a natural condition, that is utilized to collect leachate.

Scrubbing: The removal of impurities from a gas stream by spraying of a fluid.

Secondary Burner: A burner installed in the secondary combustion chamber of an incinerator to maintain a minimum temperature and to complete the combustion of incompletely burned gas.

Secondary Combustion Air: The air introduced above or below the fuel (water) bed by a natural, induced, or forced draft.

Secure Landfill: Constructed in cell forms to segregate and isolate hazardous materials from each other and from contact with groundwater or atmosphere.

Settling Velocity: The velocity at which a given dust will fall out of dust-laden gas under the influence of gravity only; also called terminal velocity.

Shredder: A machine used to break up waste materials into smaller pieces by cutting or tearing.

Siftings: The fine materials that fall from a fuel bed through its grate openings during incineration.

Slag: The more or less completely fused and vitrified matter separated during the reduction of metal from its ore.

Sliding Damper: A plate normally installed perpendicular to the flow of gas in a breeching and arranged to slide across it to regulate the flow.

Slurry: A pumpable mixture of solids and fluid.

Smog: The irritating haze resulting from the sun's effect on certain pollutants in the air.

Smoke: Particles suspended in air after incomplete combustion of materials containing carbon.

Soil, Intermediate Cover: Soil material placed on completed lifts in areas where there is clear intention to place another lift on top within one year.

Solid Waste: Any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility, and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities.

Soot: Carbon dust formed by incomplete combustion.

Source Reduction: Reducing the amount of materials entering the waste stream by voluntary or mandatory programs to eliminate the generation of waste.

Source Separation: The segregation of various wastes at the point of generation.

Spray Chamber: A chamber equipped with water sprays that cool and clean the combustion products passing through it.

Stack: Any chimney, flue, vent, roof monitor, conduit, or duct arranged to discharge emissions to the ambient air.

Stoichiometric Combustion: Combustion with the theoretical air quantity.

Stoker: A mechanical device to feed solid fuel or solid waste to a furnace.

Storage: When used in connection with hazardous waste, means the containment of hazardous waste, either on a temporary basis or for a period of years, in such a manner as not to constitute disposal of such hazardous waste.

Supernatant: The liquid remaining above a layer of settleable solids after the solids are collected at the bottom of a vessel.

Teratogenic: Affecting the genetic characteristics of an organism so as to cause its offspring to be misshapen or malformed.

Theoretical Air: The quantity of air, calculated from the chemical composition of a waste, that is required to burn the waste completely.

Thermal Efficiency: The ratio of heat used to total heat generated.

Toxic Waste: A waste which can produce injury upon contact with, or by accumulation in, a susceptible site in or on the body of a living organism.

Traveling Grate Stoker: A stoker that is essentially a moving chain belt carried on sprockets and covered with separated, small metal pieces called keys.

Trommel: A perforated, rotating, horizontal cylinder that may be used in resource recovery facilities to break open trash bags, to remove glass and such small items as stone and dirt, and to remove cans from incinerator residue.

Tuyeres: Openings or ports in a grate through which air can be directed to improve combustion.

Underfire Air: Forced or induced combustion air (quantity and direction are controlled) introduced under a grate to promote burning within a fuel bed.

Unit-Suspended Wall: A furnace wall or panel that is hung from a steel structure.

Unreclaimable Residues: Residual materials of little or no value remaining after incineration.

Vapour: The gaseous phase of substances that are liquid or solid at atmospheric temperature and pressure; e.g., steam.

Vapour Plume: The stack effluent consisting of flue gases made visible by condensed water droplets or mist.

Volatility: The property of a substance or substances to convert into vapour or gas without chemical change.

Waterwall Incinerator: An incinerator whose furnace walls consist of vertically arranged metal tubes through which water passes and absorbs the radiant energy from burning solid waste.

Wet Air Oxidation: A process by which organic materials suspended or dissolved in water can be substantially degraded (oxidized) by reacting with dissolved oxygen at high temperatures and pressures.

Windbox: A chamber below a furnace grate or surrounding a burner, through which air is supplied under pressure to burn the fuel.

Appendix B

REGULATORY AND APPROVALS INFORMATION

- Relevant Sections of the National Building Code of Canada 1985, Concerning Incinerator Design
- Ministry Policies related to incineration
- Ministry of the Environment Head and Regional Offices
- Application for a Certificate of Approval (Air)
- Application for a Certificate of Approval for a Waste Disposal Site (Processing)
- Application for the Approval of Plans and Specifications for the Construction of Works for the Collection, Transmission, Treatment, and Disposal of Industrial Wastewater

Relevant Sections of the National Building Code of Canada 1985 Concerning Incinerator Design

Section 3.5.2.5(1.) Service rooms containing an incinerator must be separated from the remainder of the building by a fire separation having a fire-resistance rating of at least 2 hours. (2.) Service rooms containing an incinerator shall not contain other fuel-fired appliances.

Section 3.5.2.7 Swing-type doors from an incinerator room shall swing outward, except that the door shall swing inward when the door opens on a corridor or any room for assembly purposes.

Section 6.2.6.1 The design, construction, installation and alteration of every indoor incinerator shall conform to NFPA (National Fire Prevention Association) 82, "Incinerators, Waste and Linen Handling Systems and Equipment".

Section 6.2.6.2 Every incinerator shall be served by a chimney flue conforming to section 6.3 of the code.

Ministry
of the
Environment
Ontario

M.O.E. Policy Manual

POLICY TITLE **THE COMBUSTION OF REFUSE IN INCINERATORS**

NO
01-01-01

Legislative Authority

the Environmental Protection Act
Regulation 308

Statement of Principles

This policy is designed to reduce contaminant emissions from incinerators by properly controlling the combustion process, and thereby to contribute to the protection of the environment. The policy establishes design and operating guidelines for application to new incinerators that burn one or a combination of domestic, commercial or non-hazardous solid industrial wastes.

Incinerators which meet the requirements of this guideline will achieve high combustion efficiencies, which will minimize the emissions of organics including toxic chlorinated compounds.

This policy refers only to the combustion process; additional emissions control and monitoring may also be required.

1. Incineration Temperature — Refuse incinerators shall be designed for a minimum of at least 1100°C, and shall operate at a destruction temperature of not less than 1000°C.

Point of Contact

Director, Air Resources Branch

Effective Date

April 27, 1987

2. **Residence Time**

Refuse incinerators shall be designed for a combustion gas residence time of not less than one second at 1000°C. This residence time is to be calculated from the point where most of the combustion has been completed and the incineration temperature fully developed.

2.1 In multi-chamber incinerators this residence time is calculated from the secondary burner(s) flame front or final secondary air injection point(s).

2.2 Where the furnace is one continuous space, such as in spreader stoker and single chamber mass burning designs, the location of the complete combustion/fully developed temperature point must be determined by an overall design review.

3. **Oxygen Availability**

Refuse incinerators shall be designed to provide not less than 6% residual oxygen in the flue gas exhaust from the incinerator or secondary chamber.

4. **Turbulence and Mixing**

Refuse incinerators shall be designed to provide a high degree of gas phase turbulence and mixing in the secondary combustion zone. Provisions shall include any combination of: appropriately located/directed air jets, changes of flue gas flow direction, baffling, and constriction of cross-sectional flue gas flow area.

5. **Range of Operation**

Refuse incinerators shall be designed to achieve the temperature, residence time, oxygen availability and turbulence requirements of this guideline over the complete expected range of values of the incinerator operating parameters, including:

- feed rate, ultimate analysis, heating value, ash and moisture contents;
- combustion air;
- flue gas flow rates; and
- heat losses.

6. Control and Monitoring

6.1 Control and monitoring systems on refuse incinerators shall be sufficient to ensure, and readily indicate and confirm, that the requirements of this guideline as well as other Ontario Ministry of the Environment standards, regulations and guidelines are consistently met. The controls and monitors shall be capable of readily signalling poor operation so that corrective action can be taken or the incinerator shut down.

6.2 Continuously monitored parameters shall include temperature(s), total hydrocarbons (or carbon monoxide), and opacity. Additionally oxygen, carbon dioxide, incinerator exhaust flue gas volume, hydrogen chloride, sulphur dioxide and nitrogen oxides monitoring may be required.

Ministry
of the
Environment
Ontario

M.O.E. Policy Manual

POLICY TITLE Air Pollution Control on Refuse Incinerators	NO 01-03

Legislative Authority

The Environmental Protection Act
Regulation 309

Statement of Principles

State-of-the-art air pollution control systems shall be installed on all new incinerators which burn one or a combination of domestic, commercial or non-hazardous solid industrial wastes. This will reduce contaminant emissions from incineration systems and thereby contribute to the protection of the environment.

This policy will assist in the interpretation of Regulation 309, Sec. 9(4), and refers only to the air pollution control (APC) system and Policy 01-01 - the Combustion of Refuse in Incinerators. For discussion purposes, the Ministry has prepared an Interim Guideline for Control on Refuse Incinerators which further defines state-of-the-art requirements.

Point of Contact

Director, Air Resources Branch

Effective Date

November 2, 1987

INTERIM GUIDELINE FOR AIR POLLUTION CONTROL ON REFUSE INCINERATORS

This interim guideline has been prepared for discussion purposes in interpreting the Ministry Policy on Air Pollution Control on Refuse Incinerators (01-03). The emission limits below have been developed based on available test data on existing installations. It will be reviewed and refined from time to time to reflect the anticipated increase in test result data from Ontario and other sources, and the anticipated development of control guidelines and/or regulations by the Canadian federal government and others.

1. Particulate Outlet Concentration

   APC systems on refuse incinerators shall have a maximum guaranteed outlet particulate loading of not greater than 20 mg/Rm^3 @ 11% O_2 (milligrams per dry cubic metre normalized to 11% oxygen at a reference (R) temperature of 25°C and a reference pressure of 101.3 kPa).

2. Hydrochloric Acid (HCl) Removal

   APC systems on refuse incinerators shall have a minimum guaranteed HCl removal efficiency of not less than 90%, or a maximum guaranteed HCl outlet concentration of 30 ppmv @ 11% O_2 (parts per million by dry volume normalized to 11% oxygen). (30 ppmv @ 11% O_2 is equivalent to about 50 mg/dry m^3 @ 25°C and 11% O_2).

3. Other Contaminants

   Incinerator systems which meet the above requirements and Policy 01-01 will minimize the formation of organics including toxic chlorinated compounds, and minimize their emission into the ambient air. Control systems which achieve the requirements of this policy will also reduce the emissions of metals (including beryllium, arsenic, cadmium, chromium, mercury, nickel, lead, selenium, antimony and zinc) and metallic compounds, and acidic gases (including sulphur dioxide (SO_2), hydrogen bromide (HBr) and hydrogen fluoride (HF)).

4. Performance Testing and Monitoring

4.1 The guaranteed removal efficiency and/or outlet loadings as described above shall be demonstrated by performance test programs approved by the Air Resources Branch and, where applicable, by methods included in the Source Testing Code (Version #2, ARB-TDA-66-80) and any revisions and/or addenda thereto.

4.2 Performance tests shall be undertaken within 3 months of startup and thereafter on an annual basis. The performance test results shall be used to define the acceptable range of readings for continuous monitoring devices, and any exceedance of this acceptable range for any monitor shall be reported to the local District Office of the Ministry of the Environment.

27 October 1987

RE1527

MINISTRY OF THE ENVIRONMENT HEAD AND REGIONAL OFFICES
Environmental Approvals and Project Engineering Branch

Head Office

8th Floor 135 St. Clair Avenue, West
Toronto, Ontario
M4V 1P5
(416) 323-4397

Central Region

Toronto Regional and District Office
4th Floor 7 Overlea Boulevard
Toronto, Ontario
M4H 1A8
(416) 424-3000

Barrie District Office
12 Fairview Road
Barrie, Ontario
L4N 4P3
(705) 726-1730

Halton-Peel District Office
1226 White Oaks Boulevard
Oakville, Ontario
L6H 2B9
(416) 844-5747

Muskoka Haliburton District Office
Gravenhurst Plaza General Delivery
Gravenhurst, Ontario
P0C 1G0
(705) 687-3408

Peterborough District Office
139 George Street North
Peterborough, Ontario
K9J 3G6
(705) 743-3972

York Durham District Office
4th Floor 7 Overlea Boulevard
Toronto, Ontario
M4H 1A8
(416) 424-3000

Northeastern Region

Sudbury Regional and District Office
11th Floor 199 Larch Street
Sudbury, Ontario
P3E 5P9
(705) 675-4501

North Bay District Office
Northgate Plaza
1500 Fisher Street
North Bay, Ontario
P1B 2H3
(705) 476-1001

Parry Sound Sub Office
74 Church Street
Parry Sound, Ontario
P2A 1Z1
(705) 746-2139

Sault Ste. Marie District Office
445 Albert Street East
Sault Ste. Marie, Ontario
P6A 2S9
(705) 949-4640

Timmins District Office
83 Algouguin Boulevard West
Timmins, Ontario
P4N 2R4
(705) 264-9474

Northwestern Region

Thunder Bay Regional and District Office
P.O. Box 5000
3rd Floor 435 James Street South
Thunder Bay, Ontario
P7C 5G6
(705) 264-9474

Kenora District Office
P.O. Box 5150
808 Robertson Street
Kenora, Ontario
P4N 1X9
(807) 468-5578

Southeastern Region

Kingston Regional and District Office
P.O. Box 820
133 Dalton Avenue
Kingston, Ontario
K7L 4X6
(613) 549-4000

Belleville Sub Office
15 Victoria Avenue
Belleville, Ontario
K8N 1Z5
(613) 962-9208

Cornwall District Office
2nd Floor 4 Montreal Road
Cornwall, Ontario
K6H 1B1
(613) 933-7402

Ottawa District Office
2378 Holly Lane
Ottawa, Ontario
K1V 7P1
(613) 521-3450

Pembroke Sub Office
1000 Mackay Street
Pembroke, Ontario
K8B 1A3
(613) 732-3643

Southwestern Region

London Regional and District Office
985 Adelaide Street South
London, Ontario
N6E 1V3
(519) 661-2200

Chatham Sub Office
c/o Min. Agriculture & Food
P.O. Box 726
435 Grand Avenue West
Chatham, Ontario
N7M 5L1
(519) 354-2150

Clinton Sub Office
c/o Min. Agriculture & Food
P.O. Box 688
Clinton, Ontario
N0M 1L0
(519) 482-3428

Owen Sound District Office
1180 - 20 Street
Owen Sound, Ontario
N4K 6H6
(519) 371-2901

Sarnia District Office
Suite 109
265 North Front Street
Sarnia, Ontario
N7T 7X1
(519) 336-4030

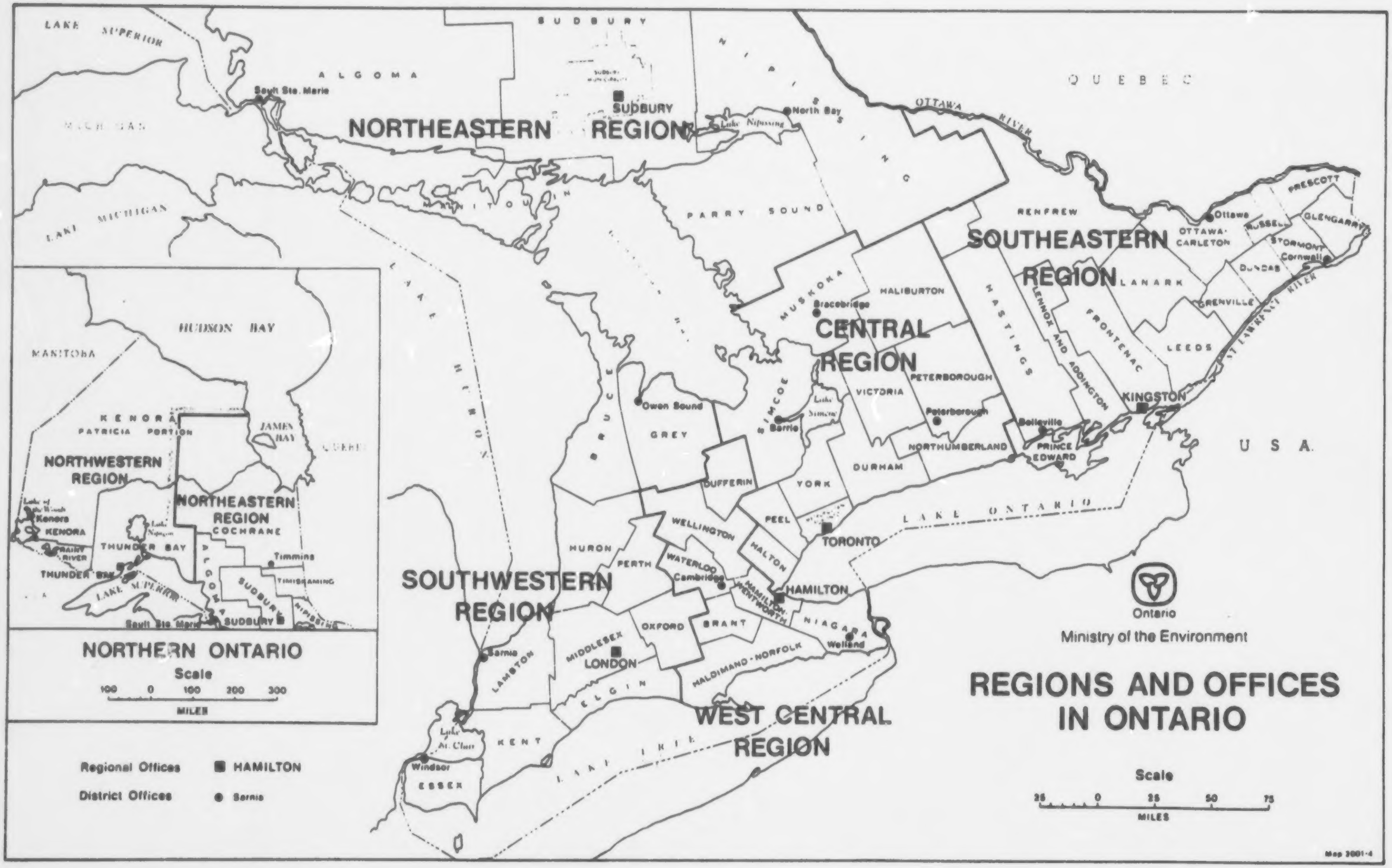
Windsor District Office
6th Floor
250 Windsor Avenue
Windsor, Ontario
N9A 6V9
(814) 254-2546

West Central Region

Hamilton Regional and District Office
P.O. Box 2112
12th Floor, 119 King Street West
Hamilton, Ontario
L8N 3Z9
(416) 521-7652

Cambridge District Office
P.O. Box 219
400 Clyde Road
Cambridge, Ontario
N1R 5T8
(519) 623-2080

Welland District Office
637 - 641 Niagara Street North
Welland, Ontario
L3C 1L9
(416) 735-0431



REGIONS AND OFFICES IN ONTARIO

Ministry of the Environment

Ontario
Regional Offices ■ HAMILTON
District Offices ● Sarnia
Scale
25 0 25 50 75
MILES
Map 3001-4
NORTHERN ONTARIO
Scale
100 0 100 200 300
MILES
NORTHEASTERN REGION
SOUTHEASTERN REGION
CENTRAL REGION
SOUTHWESTERN REGION
WEST CENTRAL REGION
NORTHWESTERN REGION
QUEBEC
U S A.
MICHIGAN
MANITOBA
HUDSON BAY
JAMES BAY
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
OTTAWA RIVER
ST. LAWRENCE RIVER
Lake Nipissing
Lake Simcoe
Lake St. Clair
Lake Nipigon
Lake of the Woods
ALGOMA
SUDBURY
NIPISSING
MANITOULIN
PARRY SOUND
MUSKOKA
HALIBURTON
RENFREW
HASTINGS
LENNOX AND ADDINGTON
FRONTENAC
LANARK
LEEDS
GRENVILLE
DUNDAS
STORMONT
GLENGARRY
PRESCOTT
RUSSELL
OTTAWA-CARLETON
PETERBOROUGH
VICTORIA
NORTHUMBERLAND
PRINCE EDWARD
DURHAM
YORK
PEEL
HALTON
SIMCOE
DUFFERIN
GREY
BRUCE
HURON
PERTH
WELLINGTON
WATERLOO
HAMILTON-WENTWORTH
NIAGARA
BRANT
OXFORD
MIDDLESEX
ELGIN
HALDIMAND-NORFOLK
LAMBTON
KENT
ESSEX
KENORA
PATRICIA PORTION
THUNDER BAY
COCHRANE
TIMISKAMING
RAINY RIVER
Sault Ste. Marie
SUDBURY
North Bay
Ottawa
Cornwall
KINGSTON
Belleville
Peterborough
Bracebridge
Barrie
Owen Sound
TORONTO
HAMILTON
Cambridge
Welland
LONDON
Sarnia
Windsor
Kenora
Thunder Bay
Timmins

Ontario

Ministry
of the
Environment

Ministère
de
l'Environnement

Application for a Certificate of Approval (Air)
Demande de certificat d'autorisation (Air)

Ministry Use Only
Réservé à l'administration
No.
N°
Date
Date

In accordance with Section 8 of the Environmental Protection Act, the undersigned hereby applies for approval of plans and specifications for:

Conformément à l'article 8 de la Loi sur la protection de l'environnement, le soussigné, fait une demande d'approbation des plans et cahier des charges pour:

☐ Construction of a plant, factory, structure or manufacturing process as referred to in Section 8(1)(a) of the Act.
La construction d'une usine, d'une installation, d'un appareil ou d'un procédé de fabrication tel qu'il en est fait mention à l'alinéa 8(1)(a) de la loi.

☐ Installation of emission control equipment as referred to in Section 8(1)(a).
L'installation d'un équipement de contrôle des émissions tel qu'il en est fait mention à l'alinéa 8(1)(a).

☐ A change of process, or increased production of a plant, referred to in Section 8(1)(b) consisting of:
Une modification de procédé ou une augmentation de débit de production tel qu'il en est fait mention à l'alinéa 8(1)(b) consistant en:

(Brief Description of Proposal as Related to this Application)
(Brève description de la proposition intéressant la présente demande)

Applicant
Demandeur
☐ Owner *Propriétaire* ☐ Agent *Agent*

Name
Nom

Telephone
Téléphone

Title
Titre

Company
Compagnie

Mailing Address
Adresse postale

1. Owner of Plant or Emission Control Equipment
Propriétaire de l'usine ou de l'équipement de contrôle des émissions

Telephone
Téléphone

Mailing Address
Adresse postale

2. Location of Plant or Emission Control Equipment
Adresse de l'usine ou de l'équipement de contrôle des émissions

Street & No. or Lot and Concession
Rue et n° ou lot et concession n°

City/Town
Ville ou canton

County
Comté

3. Plans and Specifications Prepared by
Plans et cahier des charges préparés par

Telephone
Téléphone

Mailing Address
Adresse postale

4. Description of manufacturing or production process with emphasis on sources of emission to be exhausted from the plant.
Description du procédé de fabrication ou de production en précisant les sources d'émissions produites par l'usine.

Additional Info. Enclosed?
Renseignements complémentaires ci-joints?
☐ Yes *Oui* ☐ No *Non*

5. **Production Data**
Données de production

List principal materials used and products produced in the plant or part of the plant under consideration giving volume, weight, or quantity per day, week or other production period.

Énumérer les principaux matériaux utilisés ainsi que les produits fabriqués dans l'usine ou dans la partie de l'usine considérée, en indiquant les volumes, les poids ou les quantités par jour, par semaine ou pour toute autre période de production.

Raw Materials
Matières premières

Products
Produits

Current Production Level
Niveau de production actuel

Future Production Level and Date
Niveau futur de production et date

6. Industrial Operating Schedule
Horaire et calendrier d'exploitation

Hours per Day *Heures par jour*	Days per Week *Jours par semaine*	Weeks per Year *Semaines par an*	Shift Periods *Indiquer les quarts*

7. Control Equipment for Which Approval is Requested
Équipement de contrôle des émissions pour lequel une autorisation est demandée

	Number of Units *Nombre d'unités*	Pertinent Design Information (Including manufacturer's specifications and proposed operating data, if available.) *Renseignements pertinents sur la conception, y compris les caractéristiques fournies par le fabricant et, s'il y a lieu, les données d'exploitation proposées.*
Baghouse *Filtre à sacs*		
Cyclone *Cyclone*		
Scrubber *Dépoussiéreur*		
Electrostatic Precipitator *Électrofiltre*		
Paint Spray Booth & Controls *Cabine et commandes - pulvérisation de peinture*		Additional Info. Enclosed? *Renseignements complémentaires ci-joints?*
Other *Autre*		☐ Yes *Oui* ☐ No *Non*

8. Information and Drawings to be Submitted with the Application
Renseignements et dessins à présenter avec la demande

☐ A process-flow diagram and floor plan showing material flow and unit operations, including a material balance and heat balance where applicable. The points of emission and amounts involved for each contaminant must be identified on the process-flow diagram. In addition, the handling and storage of both raw materials and finished products must be shown as well as the disposition of waste products.

Un diagramme de circulation des matériaux et un plan d'étage indiquant la circulation des matériaux et le fonctionnement des unités, y compris un bilan matières et un bilan thermique s'il y a lieu. Les points d'émission et les quantités correspondant à chaque polluant doivent être indiqués sur le diagramme de circulation des matériaux du procédé de fabrication. En outre, les schémas doivent indiquer les opérations de manutention et d'entreposage des matières premières et des produits finis ainsi que les procédés d'élimination des déchets.

☐ A drawing indicating the location of proposed emission control equipment and all stacks or exhausters venting to the atmosphere including the dimensions of buildings.

Un dessin indiquant l'emplacement de l'équipement proposé de contrôle des émissions et de toutes les cheminées et tous les ventilateurs d'évacuation dégageant les émissions dans l'atmosphère, y compris les dimensions des bâtiments.

☐ A plot, roof and elevation plan, drawn to scale if possible, and showing emission points and distances to critical receptors (air intakes, openable windows, doors, etc.) on the attached building and on-property buildings. Indicate the distance from the points of emission to all property lines.

Un levé de terrain, un plan de structure du toit et une élévation, à l'échelle si possible, indiquant les points d'émission et leurs distances jusqu'aux récepteurs importants (prises d'air, fenêtres ouvertes/fermées, portes, etc.) du bâtiment et des autres bâtiments situés sur la propriété. La distance entre les points d'émission et toutes les limites de la propriété doit être indiquée.

☐ A plan showing the relation of the points of emission to off-property structures in the immediate neighbourhood. Include distance from the points of emission to the structure in question and the heights of the structure relative to the ground level elevation at the points of emission. The zoning designation and land use in the neighbourhood should also be indicated. "Immediate neighbourhood" means that area around the installation likely to be affected by airborne emissions from the installation.

Un plan indiquant la situation des points d'émission par rapport aux structures situées en dehors de la propriété mais dans le voisinage immédiat. Ce plan doit inclure les distances entre les points d'émission et la structure en question ainsi que les hauteurs de la structure par rapport au niveau du sol aux points d'émission. La désignation de zonage et l'utilisation des terres du voisinage doivent également être indiquées sur le plan. Par "voisinage immédiat", on entend la zone située autour de l'installation susceptible d'être affectée par les émissions en provenance de celle-ci.

☐ Information data sheets on the emission control equipment, or plant manufacturing facilities, as required by the Ministry for assessment purposes.

Les feuilles de renseignements sur l'équipement de contrôle des émissions ou les installations de fabrication à l'usine que demande le ministère aux fins d'évaluation.

Note: Similar information for existing processes, plants, etc. located on the same property may be required if they have not previously been submitted to the Ministry. The application will be evaluated based on all existing and proposed contaminant emission sources.

Remarque: Le ministère peut également demander des informations semblables sur les procédés, installations, etc., situés sur la même propriété, si elles ne lui ont pas été précédemment fournies. Il évaluera la demande en fonction de toutes les sources existantes et proposées d'émission des polluants.

9. Receptors on Owner's Property
Récepteurs sur la propriété du propriétaire

Distance from Emission Point to Nearest Critical Receptor (air intake, openable window, door, etc.) *Distance entre le point d'émission et le récepteur important le plus proche (prise d'air, fenêtre pouvant s'ouvrir, porte, etc.)*	Metres *mètres*

10. Surrounding Land Use Defined as Immediate Neighbourhood
Utilisation des terres avoisinantes définies comme faisant partie du voisinage immédiat

Distance from Stack to Nearest Building *Distance de la cheminée au bâtiment le plus proche* Metres *mètres*	Height of this Building *Hauteur de ce bâtiment* Metres *mètres*
Distance from Stack to Nearest Building Higher than Stack *Distance de la cheminée au bâtiment plus haut que la cheminée le plus proche* Metres *mètres*	Height of this Building *Hauteur de ce bâtiment* Metres *mètres*
Adjacent Land Use Designation *Quelle est la désignation de l'utilisation des terres adjacentes?* ☐ Commercial *Commerciale* ☐ Residential *Résidentielle* ☐ Industrial *Industrielle* ☐ Agricultural *Agricole*	Amendment to an Official Plan or Zoning By-Law Required? *Faudra-t-il apporter une modification au règlement de zonage ou au plan officiel?* ☐ Yes *Oui* ☐ No *Non*

11. General Data About Each Stack, Vent or Exhauster
Renseignements généraux à fournir sur chaque cheminée, évent ou ventilateur d'évacuation

Height Above Roof *Hauteur au-dessus du toit* Metres *mètres*	Above Grade *Par rapport au sol* Metres *mètres*	Stack Exit Diameter *Diamètre de sortie* Metres *mètres*	Construction Material *Matériaux de construction*

Volume of Exhaust Gases *Volume des gaz d'échappement* Nm^3/s Nm^3/s	Exit Temperature of Exhaust Gases *Température de sortie des gaz d'échappement* °C. °C.

Contaminants in Exhaust
Polluants évacués

If Particulate Involved, Particle Size Distribution
S'il y a des particules, distribution de la grosseur des particules

Rate of Contaminant Discharge *Débit d'évacuation des polluants* g/s g/s	Additional Information Enclosed? *Renseignements complémentaires ci-joints?* ☐ Yes *Oui* ☐ No *Non*

12. Toxic or Hazardous Materials
Matériaux toxiques ou dangereux

List chemicals or any other materials used, produced, stored or otherwise present on plant property which could, by any means discharge toxic contaminants or potentially hazardous materials directly or indirectly into the atmosphere.

Énumérer les produits chimiques ou autres matériaux utilisés, produits, entreposés ou autrement présents sur les lieux qui pourraient, d'une façon ou d'une autre, contribuer à l'émission directe ou indirecte dans l'atmosphère de polluants toxiques ou de matériaux pouvant présenter un danger.

Name of Toxic Chemical *Nom du produit chimique toxique*	Use in Plant *Utilisation dans l'usine*	Amount Lost to Atmosphere *Quantité dispersée dans l'atmosphère*

Additional Information Enclosed?
Renseignements complémentaires ci-joints? ☐ Yes *Oui* ☐ No *Non*

13. Stock Piles
Dépôts de matériaux

Identify stock piles of raw materials, products, or any other material stored in the open that could give rise to emissions. Indicate, if applicable, methods of controlling dust emissions, such as spraying, etc.

Indiquer les dépôts de matières premières, de produits ou d'autres matériaux entreposés en plein air pouvant entraîner des émissions, et, s'il y a lieu, les méthodes prévues pour lutter contre les émissions de poussière, par ex. la pulvérisation, etc.

Additional Information Enclosed?
Renseignements complémentaires ci-joints? ☐ Yes *Oui* ☐ No *Non*

14. Noise
Bruit

What noise control measures will be undertaken as a result of the operation of the proposed manufacturing plant or emission control facility to maintain noise emission to the natural environment at satisfactory levels?

Mesures prévues pour maintenir le bruit à un niveau acceptable lors de l'exploitation de l'usine ou l'utilisation des installations de contrôle des émissions.

Additional Information Enclosed?
Renseignements complémentaires ci-joints? ☐ Yes *Oui* ☐ No *Non* ☐ Not Applicable *Sans objet*

15. Other Wastes
Autres déchets

Will this installation result in the production of liquid or solid wastes?
Cette installation entraînera-t-elle la production de déchets liquides ou solides? ☐ Yes *Oui* ☐ No *Non*

If yes, describe nature, quantity, and how they will be handled.
Si oui, décrire la nature et la quantité de ces déchets et leur mode d'élimination.

Additional Information Enclosed?
Renseignements complémentaires ci-joints? ☐ Yes *Oui* ☐ No *Non*

16. Estimated Capital Costs
Estimation du coût en capital

Cost of Manuf. Plant Process *Coût du procédé*	$	Cost of Control Equipment *Coût de l'équipement de contrôle*	$
Labour *Main-d'oeuvre*	$	Labour *Main-d'oeuvre*	$
Other *Autre*	$	Other *Autre*	$
Total *Total*	$	Total *Total*	$

Estimated Annual Operating Cost of Control Equipment
Coût d'exploitation annuel estimatif de l'équipement de contrôle $

17. Schedule
Calendrier

Proposed Starting Date for Construction *Date prévue de début des travaux*	Completion Date *Date de fin des travaux*

Declaration
Attestation

I hereby declare that the plans, specifications and information provided in this application are true and complete in every respect.
J'atteste par la présente que les plans, cahier des charges et renseignements fournis dans cette demande sont en tous points exacts et véridiques.

Applicant's Signature *Signature du demandeur*	Date *Date*

Note: If signed by an agent, written authorization duly executed by the proper officers of the owner must be attached.
Remarque: *Si la formule est signée par un agent, prière de joindre à la demande un mandat écrit dûment signé par les dirigeants de l'entreprise propriétaire.*

Checklist (To be used by applicant in assembling completed application.)
Liste de contrôle à utiliser par le demandeur pour constituer sa demande.

- ☐ Process-flow diagrams and floor plans including material and heat balances where applicable.
  Diagrammes de circulation des matériaux et plans d'étage y compris bilan matières et bilan thermique, le cas échéant.
- ☐ Plot, roof and elevation plans showing property lines, any emission points, and critical receptors related to on-property structures.
  Levé de terrain, plan de structure du toit et élévation indiquant les limites de la propriété et les points d'émission et les récepteurs importants placés sur les structures de la propriété.
- ☐ Plans showing the relation of the points of emission to off-property structures in the immediate neighbourhood.
  Plans montrant la situation des points d'émission par rapport aux structures situées en dehors de la propriété dans le voisinage immédiat.
- ☐ Drawings, design data and Ministry information sheets (if applicable) related to proposed emission control equipment.
  Dessins, notice technique du fabricant et feuilles de renseignements à l'intention du ministère (le cas échéant) sur l'équipement proposé de contrôle des émissions.
- ☐ Application duly signed.
  Demande dûment signée.

All information should be supplied in duplicate:
Tous les renseignements doivent être fournis en double exemplaire:

Mail one copy to the Ministry's local district office.

Un exemplaire doit être envoyé par la poste au bureau de district local du ministère.

Mail the second copy to:

Le deuxième exemplaire doit être envoyé par la poste à la:

Ministry of the Environment
Environmental Approvals &
Project Engineering Branch
135 St. Clair Avenue West
Toronto, Ontario M4V 1P4

Direction des approbations environnementales
et des services d'ingénierie
Ministère de l'Environnement
135 ouest, avenue St. Clair
Toronto (Ontario) M4V 1P5

Ministry Use Only ***Réservé au ministère*** ☐ Approval Recommended *Approbation de la demande recommandée*	**Examiner** ***Examinateur***	**Date** ***Date***

Ministry
of the
Environment
Ontario

APPLICATION FOR A CERTIFICATE OF APPROVAL FOR A WASTE DISPOSAL SITE (PROCESSING)

IMPORTANT NOTE:

If this application is for notification of changes in use, operations, or ownership, specify the MOE number on your certificate ________ and fill in only the data on this form which are being revised.

1. **Applicant:**

Municipal ( ) Provincial ( ) Other ( )

Name: ____________________

Address: ____________________ Postal Code: ________

City/Prov.: ____________________ Telephone: ________

If Applicant not Municipal or Provincial complete the following:

( ) Proprietorship
Name, if different than applicant: ____________________

( ) Corporation: President's Name: ____________________

( ) Partnership - Name all partners:
(i) ____________________ (ii) ____________________

2. **Land Owner:**

Name: ____________________

Address: ____________________

3. **Lessee:** (if applicable)

Name: ____________________

Address: ____________________

4. **Site Operator**

Name: ____________________ Title: ________

Address: ____________________

5. **Site Location:**

City ( )
Town ( ) Name: ____________________
Village ( )
Township ( )
Other ____________

Concession: ________
Lot No: ________
Part of Lot: ________
Street Address: ________
____

Include a copy of the plan of survey of any lands on which the site is to be located.

6. **Site Characteristics and Waste Category**

a. Present land use______________________________________

b. Present official plan designation of site ________________________

c. Present zoning category ____________________________________

d. Present land use of all adjoining properties to be provided on location map.

e. Rate at which site can receive waste per day.

Domestic_______ ( ) Tonnes ( ) Cu. Meters   Commercial_______ ( ) Tonnes ( ) Cu. Meters

Processed Organic Waste ________ ( ) Litres

If any of the following waste categories are intended to be received at the site, attached a description of each, including their source to the Application.

Liquid Industrial______ ( ) Tonnes ( ) Cu. Metres ( ) Litres   Non Hazardous Solid Industrial______ ( ) Tonnes ( )Cu. Metres ( ) Litres

Hazardous_____ ( ) Tonnes ( ) Cu. Meters ( ) Litres   Other_____ ( ) Tonnes ( ) Cu. Meters ( ) Litres

f. Number of days/year the site is open______________________________

g. Population served____

h. Names of all municipalities/major industries intended to be served by the site:

1) ____________________   4) ________________________

2) ____________________   5) ________________________

3) ____________________

i. Total area of site _____________hectares or _____________ acres

j. Estimated storage capacity: __________ ( ) Tonnes ( ) Cu. Meters ( ) Litres
(if intended for storage)
(Rate per day and estimated capacity must be in the same measurement)

k. Type of facility:

( ) incineration
( ) composting
( ) resource recovery
( ) stabilization/encapsulation
( ) packing/baling
( ) separation
( ) storage
( ) grinding/shredding
( ) other (specify):______________________________________

7. List all disposal site (for final disposal)

(i) Site Certificate No.: ____________________

Location: ____________________________________

(ii) Site Certificate No.: ________________

Location: ____________________________________

8. List all supporting documents submitted with this application:

____

____

____

____

9. **Signature**

Applicant Name (printed) ______________________________

Title ______________________________

(Signature) ______________________________

Date ______________________________

SEAL OF COMPANY
(if applicable)

Ministry
of the
Environment

Ontario

FOR OFFICE USE

APPLICATION NO.

....

DATE RECEIVED ....

APPLICATION FOR THE APPROVAL OF PLANS AND SPECIFICATIONS FOR THE CONSTRUCTION OF WORKS FOR THE COLLECTION, TRANSMISSION, TREATMENT AND DISPOSAL OF INDUSTRIAL WASTEWATER

SECTION 24, THE ONTARIO WATER RESOURCES ACT

NOTE:

(1) An application for approval shall contain the completed, attached questionnaire and appendices, and all plans, reports, etc., to satisfy items A to D below where applicable and shall be submitted in **duplicate.**

(2) Information on the Ministry's industrial pollution control policy, program and procedures is provided in the Information Brief, Environmental Approvals Branch and should be read prior to completing this form.

(3) New mines and ore milling companies are also required to complete the Ministry's Mineral Industries – Information Sheet Parts I - V.

(4) Companies establishing manufacturing or production facilities that may produce wastewater having potentially harmful waste characteristics are required to complete Biological and/or Receiving Water Quality Information Sheets together with such other information as the Ministry may require.

A. Manufacturing Plant Process Description, Water Supply and Waste Disposal

A flow diagram and a written description of the industrial manufacturing process in sufficient detail shall be submitted to indicate:

- Quantity and quality of service water used in a specific process or industrial operation (Item 6, see questionnaire)
- Quantity and measured or estimated quality of liquid waste streams arising from water or other liquid use (Items 7 and 11). In this regard, data such as bioassay results and/or data related to potential toxicity, taste and odour problems or fish tainting shall be submitted where applicable on any characteristic or component of the waste that may adversely affect the environment of the receiving watercourse.

Where the quantity and/or quality of the waste varies according to industrial operating procedure or production rate, the variation in rates of waste flow (average, maximum and minimum) and the maximum and average concentrations of the significant waste components shall be given.

B. Report on Design of Proposed Waste Treatment Works

Engineering reports on the proposed treatment works should be submitted and shall indicate:

- Expected flow and concentrations of liquid industrial wastes, and means of measuring, from all processes contributing to the treatment plant influent (Items 7 and 11).
- A flow diagram relating the proposed treatment processes.
- Function, capacity and operation of the individual components comprising the treatment facilities, and the system as a whole. Performance data should be given where possible.
- Quantities of treatment chemicals.
- Expected degree of reduction in pollutional load to be effected by the system. Supporting research or pilot plant data shall be given where possible.
- A statement setting forth the expected bacterial, physical, chemical and other known characteristics of the treated effluent (Item 13).
- Method of sludge disposal, and disposal of other solid or liquid process wastes.

C. Physical Lay-Out

1. A general arrangement or lay-out sketch of the property shall be submitted (to scale or approximate) to co-ordinate buildings, treatment or disposal works, property boundaries, municipal boundaries, effluent lines, points of discharge of outfalls in relation to the receiving water, and municipal sanitary sewer connections.

2. Also, drawings or sketches of plant areas in sufficient detail to indicate:
   - Size and location of industrial process equipment concerned.
   - Location and sizes of collection and transmission sewers including sewers transporting uncontaminated waters entering the treatment or effluent system. Existing sewers shall be differentiated from proposed sewers and direction of flow in sewers shall be shown.
   - Location of all equipment involved in the proposed treatment, control or disposal of wastes. Existing equipment shall be differentiated from proposed equipment.

D. Plans of Treatment Works

1. Engineering drawings shall include plans and profiles of each unit in the treatment or control system.
2. Plans and profiles of outfall sewers at the receiving water should also be submitted.

Under the Act, the undersigned, as owner ☐ or agent ☐ , applies for approval of plans and specifications, submitted herewith for the construction of

new industrial waste treatment or control works .... ☐

a modification or addition to existing industrial waste works .... ☐

consisting of: (brief description of proposal as related to this application)

....

....

....

....

....

and submits the following information:

1. Name of Applicant.., ...
(Company, corporation, owner) (telephone number)

....
(postal address) (county)

2. Location of Industry ....
(number, street, road or lot number, municipality, county)

NOTE: For plants producing various products or having a number of waste producing operations, items 3 to 23 which follow, should cover only details concerned with the specific proposal under consideration, including all inter-related process and treatment systems.

3. Production Data (List principal materials used and products produced, giving volume, weight, or quantity per day, week or other production period.)

Raw Materials ....

....

Products ....

....

Current Production Level ....

Future Production level and date ....

4. Industrial Operating Schedule –

hours per day ....

days per week ....

weeks per year...

indicate shift periods...

5. Number of Employees:

Office (Admin., Management) ....

Production ....

6. Water Supply:

			Litres Per Day	
	Source of Water	Average	Maximum	Minimum
(a) Industrial Processes	....	....	....	....
	....	....	....	....
	....	....	....	....
(b) Cooling, Condensers, Compressors	....	....	....	....
(c) Drinking and Sanitary	....	....	....	....
(d) Other	....	....	....	....
TOTAL SUPPLY		....	....	....

If daily supply varies from above total, explain in appendix.................................. ☐

NOTE: If water in excess of 50,000 litres per day is to be taken from other than a municipal water supply, approval is required from the Ministry's Water Resources Branch, Toronto. (Section 20, Ontario Water Resources Act).

7. Waste Disposal:

	Origin of Wastes or Description	Litres Per Day		
		Average	Maximum	Minimum
(a) Process Waste Streams (itemize)	....	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
(b) Batch Discharges	....	....	....	....
	....	....	....	....
	....	....	....	....
(c) Cooling and Condenser Water	....	....	....	....
(d) Sanitary Sewage	....	....	....	....
(e) Other	....	....	....	....
TOTAL		....	....	....

If combined daily waste flow for disposal varies from above total, explain in appendix .... ☐

8. Proposed route to, and ultimate point of waste discharge (municipal sewer, surface drain, lake, river, pond, leaching pit, etc. Give name of surface drain, lake or river. If discharge is to a tributary, also give name of main watercourse).

(a) Process Wastes (itemize) ....

....

(b) Batch Discharges ....

....

(c) Cooling and Condenser Water ....

(d) Sanitary Sewage ....

(e) Other ....

9. Where a new connection or an increased effluent discharge to a municipal sewer is proposed, municipal authorization is required. Has this authorization been obtained?

Yes ☐ No ☐

10. List all chemicals used, produced, stored, or otherwise present on plant property which could, by any means, drain, gain access or be discharged directly or indirectly in any effluent or waste flow leaving the plant or plant property.

Name of Chemical	Use of Chemical in Plant	Amount Lost to Effluent or Watercourse
....	....	....
....	....	....
....	....	....
....	....	....

See appendix for discussion .... ☐

11. **Thermal Characteristics**

(a) **Water Supplies**

What are the expected temperatures in °C of the industrial process and cooling water supplies outlined in Section 6?

	(May – October)		(November – April)	
Process:	Avg........°C	Max.......°C	Avg........°C	Max........°C
Cooling:	Avg........°C	Max.......°C	Avg........°C	Max........°C

(b) Waste Streams

What are the expected temperatures in °C of the treated effluents or process wastewater and spent cooling water streams outlined in Section 7?

	(May – October)		(November – April)	
Process or treated effluents (itemize)	Avg.......°C	Max.........°C	Avg........°C	Max.......°C
	......	....	....	....
....	......	....	......	....
....	......	....	....	....
....	......	....	....	....
....	......	....	....	....
....	......	....	....	....
Cooling water	......	....	....	....

(c) If the waste streams listed in (b) are to be combined with existing waste discharges, what are the expected temperatures and volumetric flow rates of each combined discharge?

Combined discharge description	(May – October) Avg........°C	Max........°C	(November – April) Avg........°C	Max........°C	Combine flow – Litres per day Avg.	Max.
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....

12. Expected Characteristics of Waste Effluents before treatment

....

....

....

See appendix for analytical detail .... ☐

13. Expected Characteristics of treated waste flows and final effluent

....

....

....

See appendix for analytical detail .... ☐

14. Proposed method of treated effluent flow measurement

continuous flow recording device.. ☐

non-recording device.. ☐

other .... ☐

see appendix .... ☐

15. Proposed Effluent Quality Monitoring Program (See Information Brief)

(a) automatic continuous sampling.. ☐

periodic composite sampling .... ☐

periodic grab samples .... ☐

Sampling frequency once per shift ☐ daily ☐ weekly ☐ monthly ☐ batch ☐

(b) Samples to be analyzed for

BOD_5 ☐ Suspended Solids ☐ pH ☐

Others.......... ☐.................. ☐.................. ☐ .... ☐

See appendix for detail .... ☐

16. If a leaching pit, oxidation pond, or spray or land irrigation system is proposed, the distance to the nearest:

(a) Surface watercourse is .... Metres

(b) Private well is .... Metres

(c) Munipical well is .... Metres

(d) Dwelling or built-up area is .... Metres

17. Power failures – indicate the number and duration of power failures during the past five years

number and dates ....

duration of each ....

see appendix .... ☐

18. Describe facilities that will be available or precautions that will be taken to prevent the discharge of untreated wastes or the discharge of any material that could impair the quality of the receiving water in the event of power failures, treatment plant mechanical failures or manufacturing plant equipment failures involving spills or leaks. (Items such as standby pumps, emergency holding tanks, spill ponds, etc., are to be included here.)

....

....

....

....

....

See appendix .... ☐

19. Are any solid wastes, other than those which can be picked up by the local garbage collection agency, generated in the process:

Yes ☐ No ☐

If yes, describe nature and quantity ....

....

....

20. Proposed starting date for construction of proposed industrial waste treatment or control works ....

Proposed completion date of works ....

21. Estimate of capital cost of proposed industrial waste treatment or control works ....

Breakdown of capital cost estimate

Equipment ....

Labour ....

Land ....

Other ....

Total ....

See appendix .... ☐

Engineering Charges ....

Estimate of annual costs of operation ....

22. Describe the manner in which the proposed facilities are to be operated. (Operating procedures should include schedule of operation, manpower requirements, maintenance schedule, etc. Operator qualifications should also be indicated.)

.... Appendix .... ☐

23. Study of performance or operating efficiency of installed treatment system. State:

How and when will the performance evaluation program be carried out ....

.... Appendix.... ☐

Who will make the evaluation .... Appendix .... ☐

Submitted in accordance with Section 24 and with the knowledge of Section 59, Ontario Water Resources Act.

Date ....

....
(Printed Name of Officer of Owner)

....
(Signature)

....
(Title)

NOTE: If signed by an agent, written authorization duly executed by the proper officers of the owner must accompany this application.

CHECK LIST TO BE USED BY APPLICANT IN ASSEMBLING COMPLETED APPLICATION CONSISTING OF REPORTS, PLANS, DIAGRAMS, ETC.

(1) Engineering report on treatment works – including the required information (item B) and appropriate appendices of the questionnaire .... ☐

(2) Flow diagram of manufacturing processes indicating origin of waste flows (item A) .... ☐

(3) Flow diagram of proposed waste treatment or control works (item B) .... ☐

(4) General arrangement drawing or sketch of plant property to coordinate buildings, treatment works, outfalls, etc. .... ☐

(5) Sewer layout drawing (items 4 and 5 may be combined on one drawing, if convenient). .... ☐

(6) Engineering drawings showing plans and profiles of each unit in the treatment or control system .... ☐

(7) Mineral Industries Information Sheet, if applicable .... ☐

(8) Application duly signed .... ☐

FOR OFFICE USE ONLY

....

(Name of Company or Other Owner)

Application to

MINISTRY OF THE ENVIRONMENT
ONTARIO

for Constructing

INDUSTRIAL WASTE TREATMENT WORKS

INDUSTRIAL WASTE SEWERS

MISCELLANEOUS STRUCTURES

TO THE DIRECTOR, ENVIRONMENTAL APPROVALS BRANCH

The work herein described in this application by ....

.... of ....

is recommended for approval with the issue of certificate for ....

....with the proviso

that ....

....

Date ....

Manager

Reviewed by.. Industrial Approvals Section

APPENDIX C.1

THERMODYNAMICS REFRESHER

A set of graphs and tables have been developed to allow relatively quick and reasonable calculation of incinerator parameters. The use of these materials requires familiarity with basic thermodynamic principles, which will be discussed in this appendix.

C.1.1 Equilibrium Equation

Chemical equilibrium equations are developed to indicate conservation of matter, i.e., the molecular weight on the left side of the equation equals the molecular weight on the right. For carbon:

$$C + O_2 \rightarrow CO_2$$

The atomic weight of carbon is 12.01, and of oxygen, 16.00. For this simple example, therefore, the atomic weight on the left-hand side is (1 x 12.01) + (2 x 16.00) = 44.01, which is equal to the weight of CO_2 on the right-hand side of the equation.

In the wastes and fuels normally encountered, the major constituents include carbon and hydrogen. For hydrogen:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Note that oxygen or hydrogen exist as diatomic molecules (O_2 and H_2), as does nitrogen (N_2).

The equilibrium equation for methane, CH_4, is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Note that the total molecules of each element on the left are equal to the total molecules of each element in the right (one C, four H, four O).

C.1.2 Basic Combustion Calculations

In most situations waste, or fuel, is combusted with air. Air is composed of nitrogen and oxygen. For a burning reaction to proceed, oxygen must be introduced; nitrogen will also be present along with the oxygen (3.756 molecules N_2 per molecule O_2). For carbon:

$$C + O_2 + 3.76N_2 \rightarrow CO_2 + 3.76N_2$$

The number of molecules of each substance present (moles) is proportional to the volume of that substance.

The weight of each constituent is proportional to its atomic weight. Inserting the atomic weights into this equation:

$$\begin{array}{ccccccccc}
12.01 & & 32.00 & & 28.02 & & 44.01 & & 28.02 \\
\\
C & + & O_2 & + & 3.76N_2 & \rightarrow & CO_2 & + & 3.76N_2 \\
\\
12.01 & & 32.00 & & 106.36 & & 44.01 & & 105.36 \\
\\
1.00 & & 2.66 & & 8.77 & & 3.66 & & 8.77
\end{array}$$

The first line beneath this equilibrium equation represents the total weight of each element present as calculated from its molecular weight above the equation. The second line relates each element to one kilogram of carbon and is obtained by dividing the constituent weights by the molecular weight of carbon, 12.01.

Note first that the sum of the constituent weights on one side, 12.01 + 32.00 + 105.36 = 149.37, equals that on the other side of the equation, 44.01 + 105.36 = 149.37. Likewise, normalized to one kilogram of carbon, the constituent weights are equal, one side to the other: 1.00 + 2.66 + 6.77 = 12.43, 3.66 + 8.77 = 12.43.

By normalizing this reaction to one kilogram of carbon, the determination that follows is apparent.

For burning one kilogram of carbon, 2.66 kilograms of O_2 are required, 2.66 + 8.77 = 11.43 kilograms of air are required, 3.66 kilograms of CO_2 are generated, and 3.66 + 8.77 = 12.43 kilograms of combustion products are produced.

Applying similar calculations to the combustion of hydrogen gives:

$$\begin{array}{ccccccccc}
2.02 & & 32.00 & & 28.02 & & 18.02 & & 28.02 \\
\\
2H_2 & + & O_2 & + & 3.76N_2 & \rightarrow & 2H_2O & + & 3.76N_2 \\
\\
4.04 & & 32.00 & & 105.26 & & 35.04 & & 105.36 \\
\\
1.00 & & 7.92 & & 26.08 & & 8.92 & & 26.08
\end{array}$$

Therefore, for burning one kilogram of hydrogen, 7.92 kilograms of O_2 are required, 7.92 + 26.08 = 34.00 kilograms of air are required, 8.92 kilograms of H_2O are generated, and 8.92 + 26.08 = 35.00 kilograms of combustion products are produced.

C.1.3 Stoichiometric Burning

The examples of combustion illustrated above utilized only that amount of air required for complete combustion to CO_2 or to H_2O. All the oxygen provided was used up in the generation of CO_2 and H_2O and no free oxygen was left in the products of combustion. This condition is known as complete combustion (provision of 100 percent of total air, zero excess air) and defines the stoichiometric condition. When stoichiometric air or stoichiometric oxygen is referred to, it defines the condition where only that amount of air, or oxygen, is provided to ensure complete combustion in accordance with the chemical equilibrium equation. For carbon, the stoichiometric air requirement is 11.43 kilograms per kilogram of carbon, and for hydrogen, 34.00 kilograms of stoichiometric air per kilogram of hydrogen, as previously calculated.

C.1.4 Excess Air

Combustion calculations must relate to actual burning equipment requirements if they are to have any validity. In practice, the air provided for complete burning must be greater than the stoichiometric requirement. The stoichiometric air value implies a burning process with 100 percent efficiency, where air is in contact with 100 percent of the waste (or fuel) surface, no air is wasted, and the burning reaction occurs instantaneously. In actuality, in order to achieve complete burning, an amount of air greater than the stoichiometric requirement must be provided.

For burning gaseous fuels, a total air requirement of 5 percent above stoichiometric may be sufficient, but for burning solid wastes or sludges in a multiple chamber furnace, excess air of 100 to 200 percent of stoichiometric may be required.

C.1.5 Excess Air Calculations

Burning a simple fuel, benzene (C_6H_6), at stoichiometric conditions:

78.12		32.00		28.02		44.01		18.02		28.02		
C_6H_6	+	$7.5O_2$	+	$(7.5 \times 3.76)N_2$	$\rightarrow$	$6CO_2$	+	$3H_2O$	+	$1.5O_2$	+	$33.64N_2$
78.12		240.00		790.16		264.06		54.06		790.16		
1.00		3.07		10.11		3.38		0.69		10.11		

The stoichiometric oxygen is 3.07 lb per lb C_6H_6, 7.5 moles O_2 per mole of C_6H_6. For 20% excess air an additional amount of oxygen, 20% of 7.5 or 1.5 moles of oxygen must be added to this reaction. With 7.5 moles of oxygen required for combustion of fuel, therefore, the additional 1.5 moles of oxygen added in the air will appear in the flue gas, as follows:

78.12	32.00	28.02	44.01	18.02	32.00	28.02
C_6H_6	+ $(7.5 + 1.5)O_2$	+ $(9 \times 3.76)N_2$	+ $6CO_2$	+ $3H_2O$	+ $1.5O_2$	+ $33.64N_2$
78.12	288.00	948.20	264.06	54.06	48.00	948.20
1.00	3.69	12.14	3.38	0.69	0.62	12.14

When burning a waste or fuel containing oxygen, such as cellulose ($C_6H_{10}O_5$), the main constituent of paper, calculations of excess air must consider the oxygen component of the fuel.

For stoichiometric conditions:

162.16	32.00	28.02	44.01	18.02	28.02
$C_6H_{10}O_5$	+ $6O_2$	+ $(6 \times 3.76)N_2$	+ $6CO_2$	+ $5H_2O$	+ $22.56N_2$
162.16	192.00	632.13	264.06	90.10	632.13
1.00	1.19	3.90	1.63	0.56	3.90

When calculating excess air requirements for burning, consider that 6 moles of O_2 define the stoichiometric requirements.

Therefore, for 150 percent excess air, an additional 6 x 1.5 = 9.0 moles of O_2 must be introduced, as follows:

162.16	32.00	28.02	44.01	18.02	32.00	28.02
$C_2H_{10}O_5$	+ $(6 + 9)O_2$	+ $(15 \times 3.76)N_2$	$\rightarrow 6CO_2$	+ $5H_2O$	+ $9O_2$	+ $56.40N_2$
162.16	480.00	1580.33	264.06	90.10	288.00	1580.33
1.00	2.69	9.75	1.63	0.56	1.77	9.75

C.1.6 Enthalpy

To facilitate quantification of these laws, a number of material properties have been defined. Of interest to an understanding of combustion and related processes, the total energy, or enthalpy, is of particular concern. Enthalpy, h (kJ/kg) is the total energy of a substance at one temperature relative to the energy of the same substance at another temperature. It is a relative property, and whenever it is used, it must be related to a base or datum point.

Figures C.1-1 and C.1-2 present enthalpy of water vapor and air as a function of temperature. The enthalpies are related to a base of zero degrees Celsius.

C.1.7 System Boundary

A system boundary (SB) is a definition of the entire process

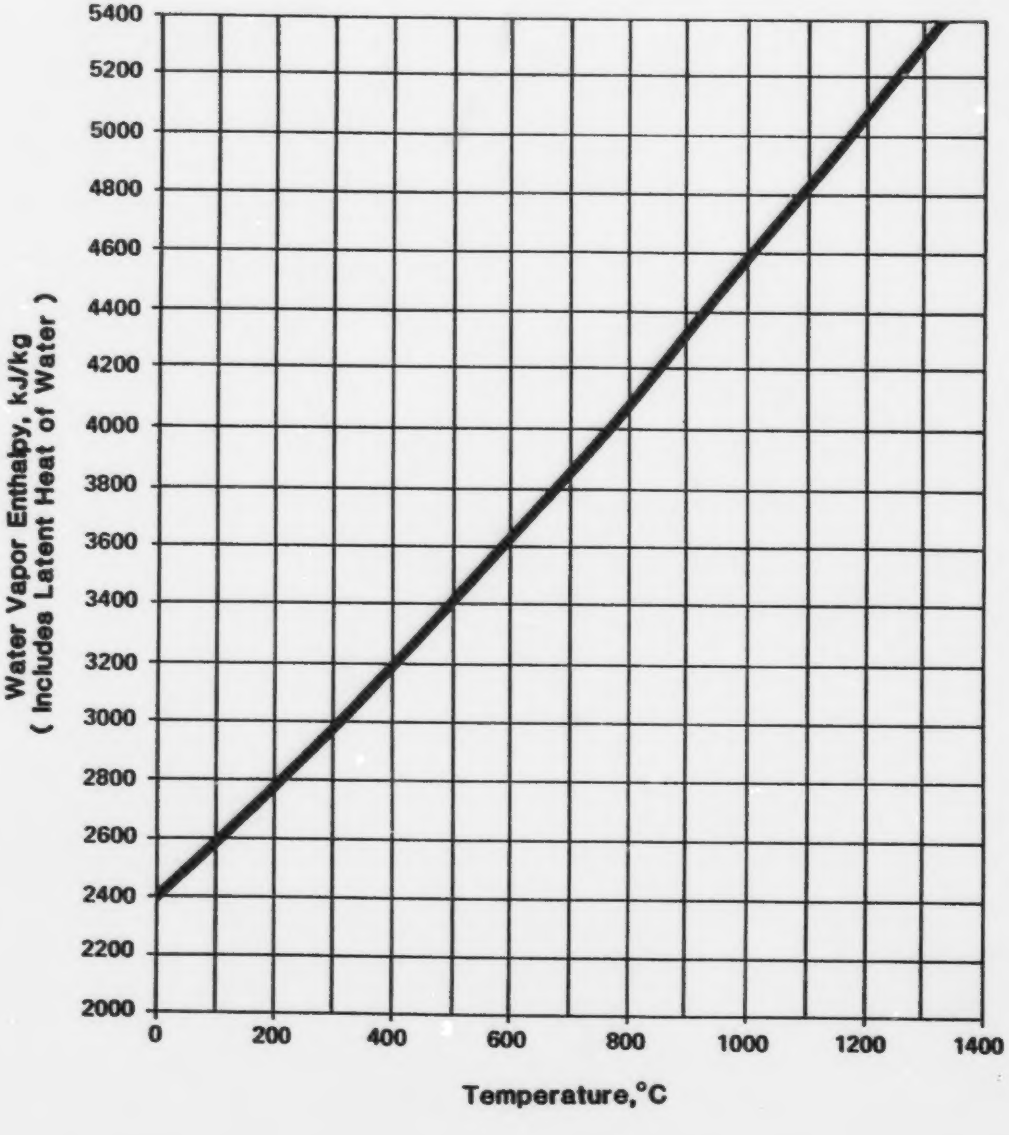


Figure C.1-1

ENTHALPY, WATER VAPOR RELATIVE TO 0°C

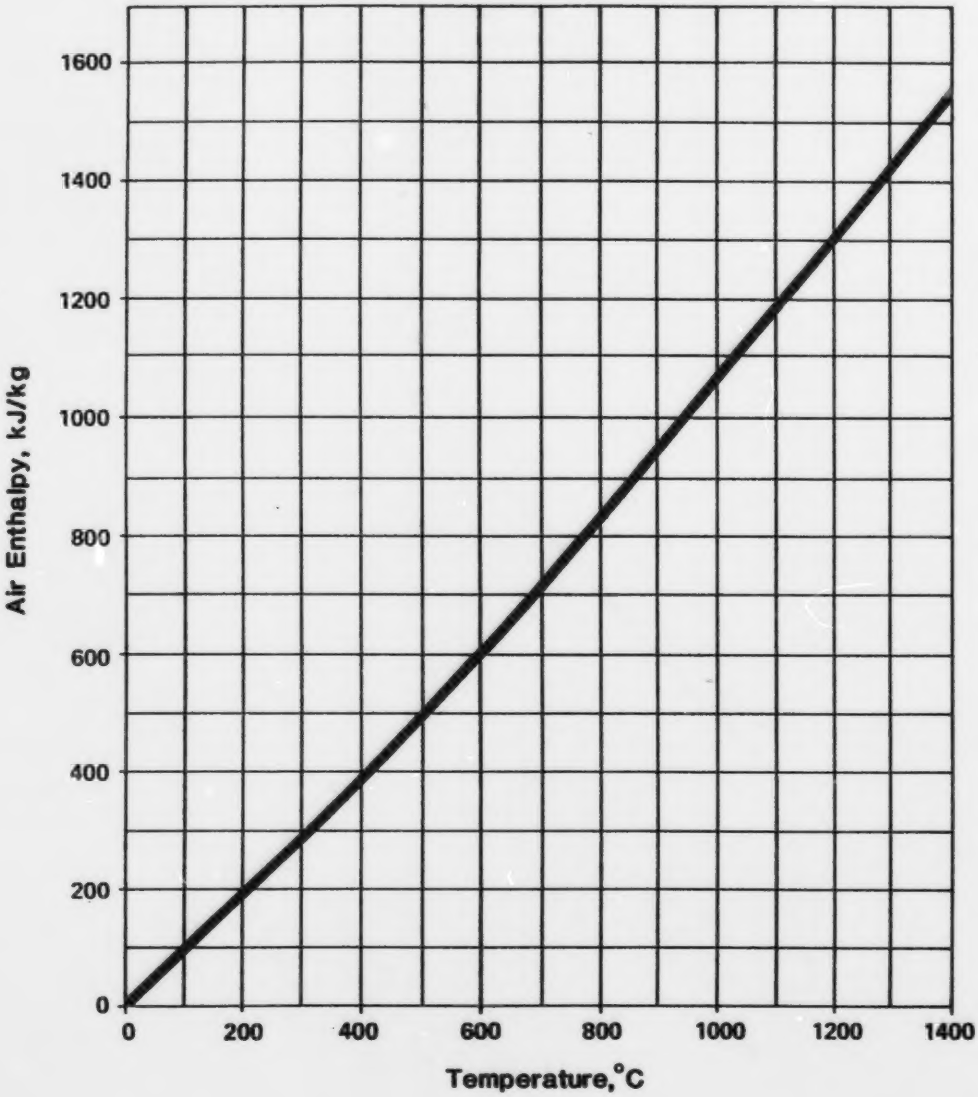


Figure C.1-2
ENTHALPY, DRY AIR RELATIVE TO 0°C

under observation. It provides a means to facilitate relationships, or calculations, relative to this process. For instance, in Figure C.1-3, the multiple hearth furnace is under observation. From the first law of thermodynamics, mass flow and heat flow across an SB must each total zero. Therefore:

Mass Flow: $M_a + M_f - M_g - M_r = 0$

Heat Flow: $Q_f + M_a h_a = M_g h_g - M_r h_r = 0$

Where Q_f is the heat of combustion of the feed (sludge) in kJ/hr, M is the mass flow in kg/hr, and h is enthalpy in kJ/kg.

C.1.8 Reaction Temperature

The temperature of a reaction can be calculated knowing the heat produced by the reaction and the quantities of products generated in the reaction. For example, if 200 kilograms of water vapor and 3000 kilograms of dry gas are produced in a reaction generating 450 000 kJ, what is the reaction temperature? This temperature is that value at which the enthalpy of the products of combustion equal the heat input to the system. A determination of reaction temperature is based on trial and error.

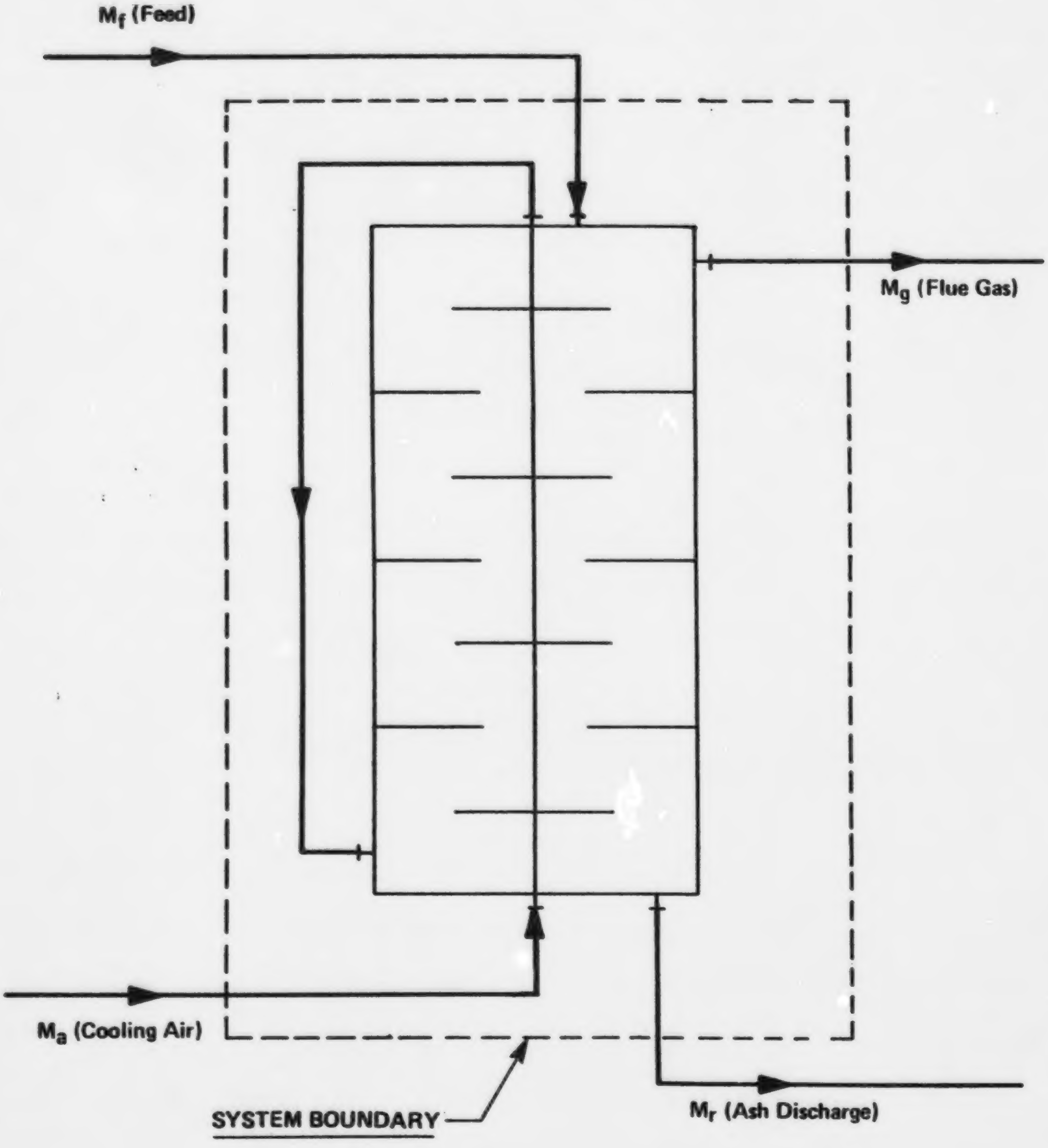

M_f (Feed)
M_g (Flue Gas)
M_a (Cooling Air)
SYSTEM BOUNDARY
M_r (Ash Discharge)

Figure C.1-3
MULTIPLE HEARTH INCINERATOR

Assume the reaction temperature in this case is 1000°C. From Figure C.1-1, at 1000°C the enthalpy of moisture is 4300 kJ/kg and from Figure C.1-2 that of air (dry gas) is 1000 kJ/kg.

Net Enthalpy:	Dry gas	1000 kJ/kg x 300 kg =	400 000 kJ
	Moisture	4300 kJ/kg x 20 kg =	86 000 kJ
	TOTAL		486 000 kJ

This total is greater than the heat generated in the reaction, 450000 kJ. A second run will be made, assuming 900°C reaction temperature:

Net Enthalpy:	Dry gas	950 kJ/kg x 300 kg =	286 000 kJ
	Moisture	41 560 kJ/kg x 20 kg =	83 000 kJ
	TOTAL		368 000 kJ

The actual temperature of the reaction is between these two assumed values and can be interpolated as follows:

Reaction temperature:

$$= 900 + \frac{(450\ 000 - 368\ 000)}{(486\ 000 - 368\ 000)} \times (1000 - 900)$$

$$= 969°\mathrm{C}$$

This example did not consider losses because of radiation from the furnace or ash discharge losses. To include these losses in this calculation, they would be subtracted from the available (generated) heat. The net result would be a decrease in reaction temperature.

APPENDIX C.2

TECHNICAL DATA

AIR COMPOSITION

	By Weight	By Volume
Oxygen in air	0.2315	0.21
Nitrogen in air	0.7685	0.79
Air to oxygen	4.3197	4.7619
Oxygen to nitrogen	0.3012	0.2658
Molecular weight, average	28.9414	

CHEMICAL ELEMENTS

Element	Symbol	Atomic No.	Atomic Weight
Actinium	Ac	89	227.
Aluminum	Al	13	26.98
Americuium	Am	95	243.
Antimony	Sb	51	121.75
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	210.
Barium	Ba	56	137.34
Berkelium	Bk	97	247.
Beryllium	Be	4	9.01
Bismuth	Bi	83	208.98
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Californium	Cf	98	251.
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Columbium (see Niobium)			
Copper	Cu	29	63.55
Curium	Cm	96	247.
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	254.
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	253.
Fluorine	F	9	19.00
Francium	Fr	87	223.
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.59
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Helium	He	2	4.00
Holmium	Ho	67	164.93
Hydrogen	H	1	1.01
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.2

Element	Symbol	Atomic No.	Atomic Weight
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lead	Pb	82	207.19
Lithium	Li	3	6.94
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Mendelevium	Md	101	256.
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	237.
Nickel	Ni	28	58.71
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	254.
Osmium	Os	76	190.2
Oxygen	O	8	16.00
Palladium	Pd	46	106.4
Phosphorus	P	15	30.97
Platinum	Pt	78	195.09
Plutonium	Pu	94	242.
Polonium	Po	84	210.
Potassium	K	19	39.10
Praseodymium	Pr	59	140.91
Promethium	Pm	61	147.
Protactinium	Pa	91	231.
Radium	Ra	88	226.
Radon	Rn	86	222.
Thenium	Re	75	186.2
Rhodium	Rh	45	102.91
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Samarium	Sm	62	150.53
Scandium	Sc	21	44.96
Selenium	Se	34	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulphur	S	16	32.06
Tantalum	Ta	73	180.95
Technetium	TC	43	99.
Tellurium	Te	52	127.60
Terbium	Tb	65	158.92

Element	Symbol	Atomic No.	Atomic Weight
Thallium	Tl	81	204.37
Thorium	Th	90	232.04
Thulium	Tm	69	168.93
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungsten	W	74	183.85
Uranium	U	92	238.03
Vanadium	V	23	50.94
Xenon	Xe	54	131.30
Yttrium	Y	39	88.91
Zinc	Zn	30	65.37
Zirconium	Zr	40	91.22

CONVERSION FACTORS

Unit	Multiplied By	Equals
Atmosphere	101,325	Pascals
Atmospheres	14.696	Pounds per square inch
Barrels (oil)	0.15899	Cubic meters
Boiler Horsepower	9.803	Kilowatts
Btu	1055.1	Joules
Btu per cubic foot	37.260	Joules per cubic meter
Btu per hour	0.29307	Watts
Btu per pound	2326	Joules per kilogram
Btu per pound per degree Fahrenheit	4187	Joules per kilogram per degree Celsius
Btu per square foot per hour	3.1546	Joules per square meter per hour
Cubic feet	0.028317	Cubic meters
Cubic yards	0.76456	Cubic meters
Feet	0.3048	Meters
Feet of water at 39.2°F	2989	Pascals
Foot pounds force	1.3558	Joules
Gallons (US)	0.003785	Cubic meters
Gallons (US)	1.201	Gallons (Imperial)
Gallons (Imperial)	0.004545	Cubic meters
Horsepower (British)	745.7	Watts
Inches of water at 60°F	248.84	Pascals
Joules	2.7778×10^{-7}	Kilowatt-hours
Kilograms	2.203	Pounds
Miles	1609.3	Meters
Pounds	0.45359	Kilograms
Pounds per cubic foot	16.018	Kilograms per cubic meter
Pounds per square inch	6894.8	Pascals
Tons	907.18	Kilogram
Watts	1	Joules per second

APPENDIX C.3

DESIGN EXAMPLES

APPENDIX C.3

DESIGN EXAMPLES

Using Table 4-4 as an outline, the following examples demonstrate the use of the techniques described in this document.

Example 1: Sludge Incineration

A stream of dewatered sludge is fed to a multiple hearth incinerator at the rate of 5000 kg/h. The sludge is 75% water. The solids are 50% noncombustible (ash), and the heating value of the combustible fraction has been determined to be 23000 kJ/kg. This is to be burned using 100% excess air with fuel oil (20% excess air) as auxiliary fuel. Standard air is available at 15.5°C and 60% relative humidity, which is equivalent to a humidity of 0.00657 kg moisture per kg of dry air. Radiant heat losses are estimated at 1% of the heat released from the waste. The ash is estimated to remove 200 kJ/kg ash from the incinerator. The exhaust gas temperature is to be maintained at 760°C.

Calculations follow and are summarized in Table C.3-1.

1. Feed rate	5000 kg/h	in example statement
2. Moisture fraction	.75	in example statement
3. Moisture quantity	5000 x 0.75 = 3750 kg/h	(1x2)
4. Solids quantity	5000 - 3750 = 1250 kg/h	(1-3)
5. Noncumbustible Fraction	0.5	in example statement
6. Noncombustible quantity	0.5 x 1250 = 625 kg/h	(4x5)
7. Combustible quantity	1250-625 = 625 kg/h	(4-6)
8. Heating value	23 000 kJ/kg combustible	in example statement
9. Heat generated	625 x 23,000 = 14.375 x 10^6kJ/h	(7x8)
10. Stoichiometric Air Ratio	7 kg air/kg combustible	From Fig. 4-2a
11. Stoichiometric Air	7 x 625 = 4375 kg/h	(7 x 10)
12. Excess Air Fraction	1.00	in example statement
13. Excess Air Required	1 x 4375 = 4375 kg/h	(11x12)
14. Total Air Required	4375 + 4375 = 8750 kg/h	(11+13)
15. Moisture generated	0.52 kg water/kg combustible	from Figure 4-2b
16. Moisture generated	625 x 0.52 = 325 kg/h	(7x15)
17. Humidity in air	.00657 kg water/kg air	from example statement
18. Humidity	0.00657 x 8750 = 57 kg/h	(14x17)
19. Total Moisture	3750 + 325 + 57 = 4132 kg/h	(3+16+18)
20. Dry flue gas	625 + 8750 - 325 = 9050 kg/h	(7+14-16)
21. Radiant heat loss	0.01 x 14.375 x 10^6 = 0.14 x 10^6 kJ/h	1%x(9)
22. Ash heat content	200 kJ/kg	in example statement

23. Ash heat loss	625 x 200 = 0.125 x 10^6 kJ/h	(6x22)
24. Humidity Correction	57 x 2186 = .125 x 10^6 kJ/h	(18)x2186
25. Miscellaneous heat loss	0	None
26. Heat in flue gas	14.375 -0.14 -.125 +.125 -0 = 14.235 x 10^6 kJ/h	(9-21-23+24-25)
27. Flue gas temperature	Calculate from Figures C.1-1 & C.1-2. Estimate temperature, check enthalpy against (26), and re-estimate: @ 200°C enthalpy of air and moisture is 190 and 2790 kJ/kg respectively. With 9050 kg/h dry gas and 4132 kg/h moisture the total enthalpy of the stream is 190 x 9050 + 2790 x 4132 = 13.25 x 10^6 kJ/h. @ 400°C the enthalpy of air and water vapor is 380 and 3200 kJ/kg respectively, for a total stream heat content of 380 x 9050 + 3200 x 4132 = 16.66 x 10^6 kJ/kg. The heat content of the flue gas, 14.235 x 10^6 kJ/h, is	

	gas, 14.235×10^6 kJ/h, is equivalent, by interpolation, to: 200 + $(400-200)\ \frac{[14.235 - 13.25]}{[16.66 - 14.235]}$ = 258°C	
28. Required gas temperature	760°C	in example statement
29. Required Enthalpy of flue gas	Calculate from required temperature and Figures C.1-1 and C.1-2: T = 760°C (From Figures C.1-1 and C.1-2) Air Enthalpy = 780 kJ/kg x 9050 kg/h = 7.06×10^6 kJ/h Water Enthalpy = 3990 kJ/kg x 4132 kg/h = 16.49×10^6 kJ/h Total Enthalpy = 23.55×10^6 kJ/h	19, 20, 27
30. Net heat required	$(23.55-14.235) \times 10^6$ = 9.315×10^6 kJ/h	29-26
31. Fuel excess air	0.2	in example statement

32. Fuel required	9.315 x 10^6 kJ/h ÷ 22 000 kJ/gal = 423 l/h	Figures 4-4, 4-5, 30, 31
33. Air required for fuel	15.03 kg/l	Table 4-5, 30
34. Air required for fuel	15.03 x 423 = 6379 kg/h	33x32
35. Moisture from fuel	1.05 kg/l	Table 4-5, 30
36. Moisture generated	1.05 x 423 = 444 kg/h	35x32
37. Dry gas from fuel	15.09 kg/l	Table 4-5, 30
38. Dry gas generated	15.09 x 423 = 6383 kg/h	37x32
39. Total dry gas flow	6383 + 9050 = 15 433 kg/h	38+20
40. Total moisture flow	444 + 4132 = 4576 kg/h	36+19
41. Total heat at exit	14.235 x 10^6 + 423 x 39 100 = 30.774 x 10^6 kJ/h	26 + 32 x (fuel gross htg. value)

Table C.3-1

SLUDGE INCINERATOR ANALYSIS

1.	Feed quantity (as received)	5000	Given
2.	Moisture fraction	.75	Given
3.	Moisture quantity (kg/h)	3750	1 x 2
4.	Solids quantity (kg/h)	1250	1 - 3
5.	Noncombustible fraction	0.50	Given
6.	Noncombustible quantity (kg/h)	625	4 x 5
7.	Combustible quantity (kg/h)	625	4 - 6
8.	Heating value (kJ/kg combustible)	23 000	Given
9.	Total heat generated (kJ/h)	14 375 000	7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	7.0	Figure 4-2
11.	Stoichiometric air (kg/h)	4375	7 x 10
12.	Excess air fraction	1.00	Given
13.	Excess air (kg/h)	4375	11 x 12
14.	Total air required (kg/h)	8750	11 + 13
15.	Moisture generated (kg/kg combustible)	0.52	Figure 4-3
16.	Moisture generated (kg/h)	325	7 x 15
17.	Humidity (kg/kg dry air)	0.00657	Given
18.	Humidity (kg/h)	57	14 x 17
19.	Total moisture (kg/h)	4132	3 + 16 + 18
20.	Dry flue gas (kg/h)	9050	7 + 14 - 16
21.	Radiation heat loss (kJ/h)	140 000	Given
22.	Ash heating value (kJ/kg)	200	Given
23.	Ash heat loss (kJ/h)	125 000	6 x 22
24.	Humidity Correction (KJ/h)	125 000	18 x 2,186
25.	Miscellaneous heat loss (kJ/h)	0	Given
26.	Heat in flue gas (kJ/h)	14 235 000	9 - 21 - 23 + 24 - 25
27.	Flue gas temperature (°C)	258	19, 20, 25
28.	Required gas temperature (°C)	760	Given
29.	Required flue gas heat content (kJ/h)	23 550 000	19, 20, 28
30.	Heat required (kJ/h)	9 315 000	29-26
31.	Fuel excess air	0.2	Given
32.	Fuel required (l or m^3/h)	423	Figures 4-3a, 30, 31
33.	Air for fuel (kg air/l or m^3)	15.03	Table 4-7, 31
34.	Air required (kg/h)	6379	33 x 32
35.	Moisture from fuel (kg/l or m^3)	1.05	Table 4-5, 31
36.	Moisture generated (kg/h)	444	35 x 31
37.	Dry gas from fuel (kg/l or m^3)	15.09	Table 4-5, 31
38.	Dry gas generated (kg/h)	6383	37 x 32
39.	Total dry gas flow (kg/h)	15 433	38 + 20
40.	Total moisture flow (kg/h)	4576	36 + 19
41.	Total heat at exit (kJ/h)	30 774 000	26 + 32 x (fuel gross htg. value)

Example 2: Refuse Incineration

Refuse, 50 tonnes per day (2083 kg/h) is to be incinerated. It has a moisture content of 24%, a heating value of 11 000 kJ/kg as received and an ash (non-combustible) content of 11%, as received. The incinerator is of grate design, requires 85% excess air for complete combustion. A minimum temperature of 980°C is required for effective burn out. Assume an ash heat content of 250 kJ/kg, 2% radiation heat loss, and a humidity of .00657 kg/kg dry air.

Calculations follow and are summarized in Table C.3-2

1. Feed rate	2083 kg/h	in example statement
2. Moisture fraction	.24	in example statement
3. Moisture quantity	2083 x .24 = 500 kg/h	(1x2)
4. Solids quantity	2083 - 500 = 1583 kg/h	(1-3)
5. Noncumbustible Fraction	0.11 ÷ (1-0.24) = 0.145	in example statement
6. Noncombustible quantity	1583 x .145 = 230 kg/h	(4x5)
7. Combustible quantity	1583 - 230 - 1353 kg/h	(4-6)
8. Heating value	11 000 x (2083/1353) = 16 935 kJ/kg	in example statement
9. Heat generated	1353 x 16 935 = 22 913 000 kJ/h	(7x8)
10. Stoichiometric Air Ratio	5.1 kg air/kg combustible	From Fig. 4-2a
11. Stoichiometric Air	1353 x 5.1 = 6900 kg/h	(7 x 10)
12. Excess Air Fraction	.85	in example statement
13. Excess Air Required	6900 x 8.5 = 5865 kJ/h	(11x12)
14. Total Air Required	6900 + 5865 = 12 765 kJ/h	(11+13)
15. Moisture generated	.43 kg water/kg combustible	from Figure 4-2b
16. Moisture generated	1353 x .43 = 582 kg/h	(7x15)
17. Humidity in air	.00657 kg water/kg air	from example statement
18. Humidity	12 765 x .00657 = 84 kg/h	(14x17)
19. Total Moisture	500 + 582 + 84 = 1166 kg/h	(3+16+18)
20. Dry flue gas	1353 + 12765 - 582 = 13 536 kg/h	(7+14-16)
21. Radiant heat loss	0.02 x 22 913 000 - 458 000 kg/h	2%x(9)
22. Ash heat content	250 kJ/kg	in example statement

23. Ash heat loss	230 x 250 = 5800 kJ/h	(6x22)
24. Humidity Correction	84 x 2186 = 184 000 kJ/h	(18)x2186
25. Miscellaneous heat loss	0	None
26. Heat in flue gas	22 913 000 - 458 000 - 58 000 + 184 000 - 0 = 22 581 000 kJ/h	(9-21-23+24-25)
27. Flue gas temperature	Calculate from Figures C.1-1. & C.1-2. Estimate temperature, check enthalpy against (26), and re-estimate: @ 1000°C enthalpy of air and moisture in 1070 and 4590 kJ/kg respectively. With 13 536 kg/h dry gas and 1166 kg/h moisture the total enthalpy of the stream is 1070 x 1356 + 4590 x 166 = 19.835x 10^6 kJ/h. @ 1200°C the enthalpy of air and moisture is 1300 and 5060 kJ/kg respectively, for a total stream heat content of 14000 x 12536 + 1166 = 23.497 x 10^6 kJ/h. The heat content of the flue gas, 22.581 x 10^6 kJ/h, is	

	equivalent, by interpolation, to: 1000 + $(1200\text{-}1000)\ \frac{[22.581 - 19.835]}{[23.497 - 19.835]}$ = 1150°C	
28. Required gas temperature	980°C	in example statement
29. Required Enthalpy of flue gas	Sufficient heat exists	19, 20, 28
30. Net heat required	none	29-26
31. Fuel excess air	--	in example statement
32. Fuel required	none	Figure 4-3a, 30, 31
33. Air required for fuel	--	Table 4-5, 31
34. Air required for fuel	--	33x32
35. Moisture from fuel	--	Table 4-5, 31
36. Moisture generated	--	35x32
37. Dry gas from fuel	--	Table 4-5, 31
38. Dry gas generated	--	37x32
39. Total dry gas flow	13 526 kg/h	38+20
40. Total moisture flow	1166 kg/h	36+19
41. Total heat at exit	22 581 000 kJ/h	26 + 32 x (fuel gross htg. value)

Table C.3-2

REFUSE INCINERATOR ANALYSIS

1.	Feed quantity (as received)	2083	Given
2.	Moisture fraction	.24	Given
3.	Moisture quantity (kg/h)	500	1 x 2
4.	Solids quantity (kg/h)	1583	1 - 3
5.	Noncombustible fraction	.145	Given
6.	Noncombustible quantity (kg/h)	230	4 x 5
7.	Combustible quantity (kg/h)	1353	4 - 6
8.	Heating value (kJ/kg combustible)	16 935	Given
9.	Total heat generated (kJ/h)	22 913 000	7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	5.1	Figure 4-2a
11.	Stoichiometric air (kg/h)	6900	7 x 10
12.	Excess air fraction	.85	Given
13.	Excess air (kg/h)	5865	11 x 12
14.	Total air required (kg/h)	12 765	11 + 13
15.	Moisture generated (kg/kg combustible)	.43	Figure 4-2b
16.	Moisture generated (kg/h)	582	7 x 15
17.	Humidity (kg/kg dry air)	.00657	Given
18.	Humidity (kg/h)	84	14 x 17
19.	Total moisture (kg/h)	1166	3 + 16 + 18
20.	Dry flue gas (kg/h)	13 536	7 + 14 - 16
21.	Radiation heat loss (kJ/h)	458 000	Given
22.	Ash heating value (kJ/kg)	250	Given
23.	Ash heat loss (kJ/h)	58 000	6 x 22
24.	Humidity Correction (kJ/h)	184 000	18 x 2186
25.	Miscellaneous heat loss (kJ/h)	0	Given
26.	Heat in flue gas (kJ/h)	22 581 000	9 - 21 + 24 - 25
27.	Flue gas temperature (°C)	1150	19, 20, 25
28.	Required gas temperature (°C)	980	Given
29.	Required flue gas heat content (kJ/h)	--	19, 20, 28
30.	Heat required (kJ/h)	--	29 - 26
31.	Fuel excess air	--	Given
32.	Fuel required (gal or m^3/l)	--	Figures 4-3a, 30, 31
33.	Air for fuel (kg air/l or m^3)	--	Table 4-5, 31
34.	Air required (kg/h)	--	33 x 32
35.	Moisture from fuel (kg/l or m^3)	--	Table 4-5, 31
36.	Moisture generated (kg/h)	--	35 x 32
37.	Dry gas from fuel (kg/l or m^3)	--	Table 4-5, 31
38.	Dry gas generated (kg/h)	--	37 x 32
39.	Total dry gas flow (kg/h)	13 536	38 + 20
40.	Total moisture flow (kg/h)	1166	36 + 19
41.	Total heat at exit (kJ/h)	22 581 000	26 + 32 (fuel gross htg. value)

Example 3: Starved Air Incinerator

For the previous example, if the release were incinerated in a starved air unit, consisting of two chambers, the total gas flow and heat release from the system would be the same. Conditions at the exit of the primary chamber could be calculated as follows assuming 60% of the stoichiometric air requirement was provided in the primary chamber:

> The heating value of the combustible content would not be fully realized in the primary chamber because only 60% of the stoichiometric air requirement is provided. From Figure C.3-1, at 60% of stoichiometric, 72% of the total heat capacity of the 16 935 combustibles is released which is 0.72 x 16935 kJ/kg = 12 193 kJ/kg. The air requirement is based on 16 935 kJ/kg while moisture generation is based on 12 193 kJ/kg actual heat release.

Calculations follow and are summarized in Table C.3-3.

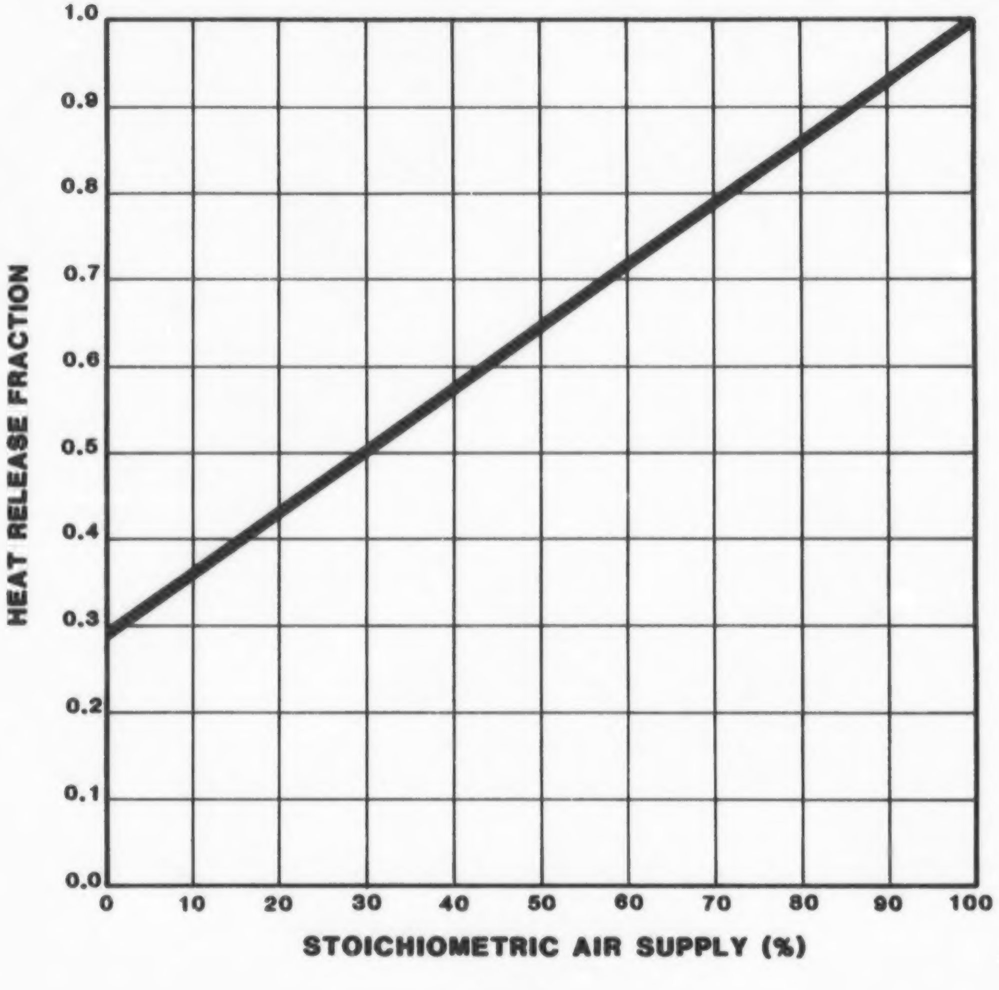


Figure C.3-1
HEAT RELEASE FRACTION vs STOICHIOMETRIC AIR SUPPLY FOR STARVED AIR COMBUSTION

1. Feed rate	2083 kg/h	in example statement
2. Moisture fraction	.24	in example statement
3. Moisture quantity	2083 x .24 = 500 kg/h	(1x2)
4. Solids quantity	2083 - 500 = 1583 kg/h	(1-3)
5. Noncumbustible Fraction	0.11 ÷ (1-0.24) = 0.145	in example statement
6. Noncombustible quantity	1583 x .145 = 230 kg/h	(4x5)
7. Combustible quantity	1583 - 230 = 1353 kg/h	(4-6)
8. Heating value	12 913 kJ/kg	in example statement
9. Heat generated	1353 x 12 193 = 16 497 000 kJ/h	(7x8)
10. Stoichiometric Air Ratio	5.1 kg air/kg combustible	From Fig. 4-2a
11. Stoichiometric Air	1353 x 5.1 = 6900 kg/h	(7 x 10)
12. Excess Air Fraction	.6 of stoichiometric	in example statement
13. Excess Air Required	6900 x .6 = 4140 kJ/h	(11x12)
14. Total Air Required	4140 kJ/h	(11+13)
15. Moisture generated	.32 kg water/kg combustible	from Figure 4-2b
16. Moisture generated	1353 x .32 = 433 kg/h	(7x15)
17. Humidity in air	.00657 kg water/kg air	from example statement
18. Humidity	4140 x .00657 = 27 kg/h	(14x17)
19. Total Moisture	500 + 433 + 27 = 960 kg/h	(3+16+18)
20. Dry flue gas	1353 + 4140 - 433 = 5060 kg/h	(7+14-16)
21. Radiant heat loss	.02 x 16 497 000 = 330 000 kJ/h	1%x(9)
22. Ash heat content	250 kJ/kg	in example statement

23. Ash heat loss	230 x 250 = 58 000 kJ/h	(6x22)
24. Humidity Correction	27 x 2186 = 59 000 kJ/h	(18)x2186
25. Miscellaneous heat loss	0	None
26. Heat in flue gas	16 497 000 - 330 000 - 58 000 + 59 000 - 0 = 16 168 000 kJ/h	(9-21-23+24-25)
27. Flue gas temperature	At 1200°C the enthalpy of air and moisture is 1300 and 5060 kJ/kg respectively. The heat content of this stream at 1200°C would be 1300 x 5060 + 5060 x 960 = 11.4 x 10^6 kJ/h which is lower than the heat in the flue gas, 16.168 x 10^6 kJ/h. The temperature exiting the primary chamber is, therefore, in excess of 1200°C.	
28. Required gas temperature	--*	in example statement
29. Required Enthalpy of flue gas	--	19, 20, 28

30. Net heat required	--	29-26
31. Fuel excess air	--	in example statement
32. Fuel required	--	Figure 4-3a, 30, 31
33. Air required for fuel	--	Table 4-5, 31
34. Air required for fuel	--	33x32
35. Moisture from fuel	--	Table 4-5, 31
36. Moisture generated	--	35x32
37. Dry gas from fuel	--	Table 4-5, 31
38. Dry gas generated	--	37x32
39. Total dry gas flow	5060	38+20
40. Total moisture flow	960	36+19
41. Total heat at exit	16 168 000	9 + 33 x (fuel gross htg. value)

Table C.3-3

STARVED AIR INCINERATOR ANALYSIS

1.	Feed quantity (as received)	2083	Given
2.	Moisture fraction	.24	Given
3.	Moisture quantity (kg/h)	500	1 x 2
4.	Solids quantity (kg/h)	1583	1 - 3
5.	Noncombustible fraction	.145	Given
6.	Noncombustible quantity (kg/h)	230	4 x 5
7.	Combustible quantity (kg/h)	1353	4 - 6
8.	Heating value (kJ/kg combustible)	12 193	Given
9.	Total heat generated (kJ/h)	16 497 000	7 x 8
10.	Stoichiometric air ratio (kg/kg combustible)	5.1	Figure 4-2a
11.	Stoichiometric air (kg/h)	6900	7 x 10
12.	Excess air fraction	.6*	Given
13.	Excess air (kg/h)	4140	11 x 12
14.	Total air required (kg/h)	4140	11 + 13
15.	Moisture generated (kg/kg combustible)	.32	Figure 4-2b
16.	Moisture generated (kg/h)	433	7 x 15
17.	Humidity (kg/kg dry air)	.00657	Given
18.	Humidity (kg/h)	27	14 x 17
19.	Total moisture (kg/h)	960	3 + 16 + 18
20.	Dry flue gas (kg/h)	5060	7 + 14 - 16
21.	Radiation heat loss (kJ/h)	330 000	Given
22.	Ash heating value (kJ/kg)	250	Given
23.	Ash heat loss (kJ/h)	58 000	6 x 22
24.	Humidity Correction (KJ/h)	59 000	18 x 2186
25.	Miscellaneous heat loss (kJ/h)	0	Given
26.	Heat in flue gas (kJ/h)	16 168 000	9 - 21 - 23 + 24 - 25
27.	Flue gas temperature (°C)	over 1200	19, 20, 25
28.	Required gas temperature (°C)	--	Given
29.	Required flue gas heat content (kJ/h)	--	19, 20, 28
30.	Heat required (kJ/h)	--	29 - 26
31.	Fuel excess air	--	Table 4-7
32.	Fuel required (gal or m^3/h)	--	Figure 4-4, 4-5 29, 31
33.	Air for fuel (kg air/l or m^3)	--	Table 4-5, 31
34.	Air required (kg/h)	--	33 x 32
35.	Moisture from fuel (kg/l or m^3)	--	Table 4-7, 31
36.	Moisture generated (kg/h)	--	35 x 32
37.	Dry gas from fuel (kg/l or m^3)	--	Table 4-7, 30
38.	Dry gas generated (kg/h)	--	37 x 32
39.	Total dry gas flow (kg/h)	5060	38 + 20
40.	Total moisture flow (kg/h)	960	36 + 19
41.	Total heat at exit (kJ/h)	16 168 000	26 + 32 x (fuel gross htg. value)

*Fraction of stoichiometric